VOL. 1 No. 7 JULY 1936

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND

IRRADIATION OF PLANTS WITH NEON LIGHT

By J. W. M. ROODENBURG and G. ZECHER.

Summary. Owing to the want of light the growth and development of plants during the winter becomes considerably arrested. This check may be completely or partly counterbalanced by irradiating the plants with artificial light. Owing to its favourable spectral distribution neon light is particularly suitable for this purpose. The technical development of neon light sources for plant irradiation and the irradiation conditions laid down by Roodenburg on the basis of extensive experimental work now permit the commercial grower and the amateur horticulturist to promote the growth of their plants by irradiation.

After decades of abortive experiments in the Netherlands and elsewhere on the artificial irradiation of plants, an appreciable measure of success has recently been achieved in this direction. That light is one of the principal factors in the growth of plants has been realised for many years, and the idea has long been entertained of attempting to influence the growth and development of plants by irradiation with artificial light. But only with the technical development of the requisite sources of light has a fundamental investigation of this problem been made possible and enabled the market grower and amateur horticulturist to employ irradiation methods on a practical scale.

Composition of light for the irradiation of plants

The life and growth of plants are intimately connected with certain chemical processes. One of the chief of these is the assimilation of carbon dioxide, in the course of which the plants absorb carbon dioxide from the air and the carbohydrates from the water of which plants are principally built up. Carbon dioxide assimilation takes place only when a light stimulus is provided, the light being absorbed by the green colouring matter of the leaves, viz, chlorophyll. If the light available for the plant drops below a specific level, e.g. during the short days of winter, growth is practically static, even though all other conditions for their growth are adequately met, as for instance by placing in heated and moist greenhouses and by the addition of suitable fertilisers.

By augmenting the natural light with an auxiliary source of illumination, it has now been possible to promote the growth of plants even during the darkest winter months.

Carbon dioxide assimilation is most active in red light, which is absorbed to a high degree by chlorophyll. Hence, in providing auxiliary irradiation for plants, it is essential to utilise a source of light containing a sufficient concentration of red rays. At an early date it was therefore proposed to employ neon light for this purpose [1]). *Fig. 1* shows the spectrum of a neon light source and the assimilation curve, the latter indicating the amount of carbohydrate formed on irradiation with an equivalent light energy of each wavelength. Neon has the most intense lines just in that region in which the effect of light on carbon dioxide assimilation is greatest. The same figure also gives the spectrum for an ordinary glowlamp. The greater part of the radiation from the glowlamp consists of infra-red (invisible) rays and only 8 per cent of its radiation is situated in the visible spectrum, whilst about 20 per cent of the total energy radiated from the neon tube lies in this region. But since glowlamp light is much easier to generate and to manipulate than neon light, experiments have also been carried out on the irradiation of plants with glowlamp light. In the first place it is necessary to produce an adequate intensity of red light. This can be readily obtained with high-power glowlamps, although at the same time an immeasurably greater amount of energy is also radiated in the undesirable region of the spectrum.

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[1]) G. Höstermann: Experiments with neon light. Bericht Königl. Gärtnerlehranstalt Dahlem, 1916-17, p. 76.

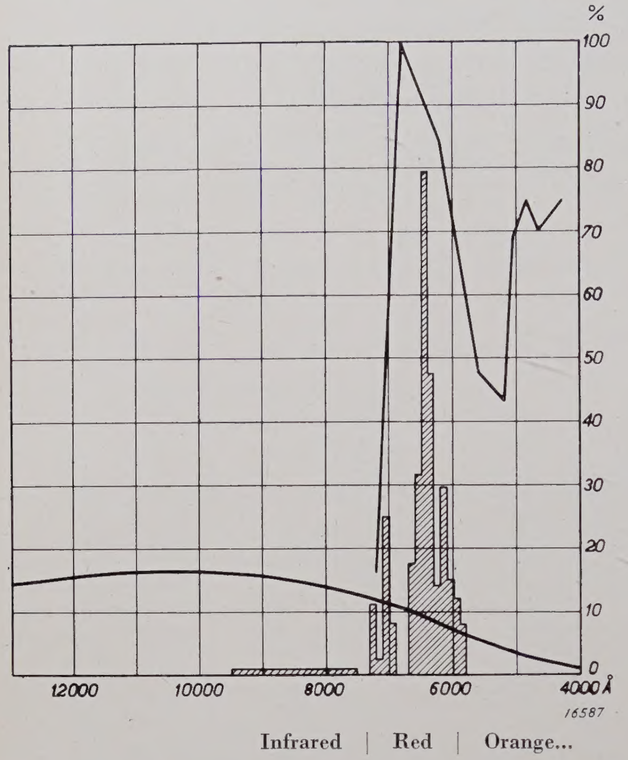
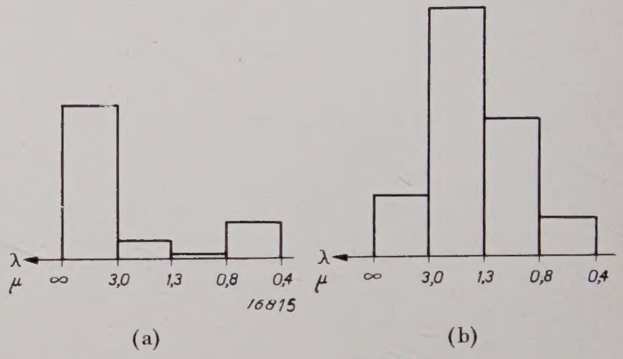


Fig. 1. Assimilation curve of plants, giving the relative amount of carbonhydrate formed on irradiation with a specific light energy at each wave length. The spectra for a neon light source and an ordinary glowlamp are also included. The strongest neon lines are situated exactly in that region of the spectrum of principal importance to assimilation, whilst maximum radiation from the glowlamp is obtained at much higher wave lengths, viz, in the infra-red.

Investigations made by **Roodenberg**[2]) gave a fresh insight into this problem in so far as they demonstrated that excess infra-red rays were not only superfluous but even deleterious to the plants. Nearly all investigators have found with glowlamp light that, although the growth of the leaves was promoted in the irradiated plants, the general quality of the plants suffered, as the stems and stalks grew too "leggy". This "legginess" is due to the high percentage of infra-red heat rays given out by glowlamps [3]).

As we have already seen, neon light also contains infra-red radiation, although there is here not the same disproportion between the infra-red and the red rays as found with the glowlamp. Moreover, the distribution of the radiated energy over the various parts of the infra-red region is here quite different, as is shown in *fig. 2*. The "infra-red" has here been divided up into three almost arbitrary ranges, viz, from a wave length of 0.8 to 1.3 μ, from 1.3 to 3 μ, and above 3 μ. The "visible" wave lengths extend from 0.4 to 0.8. Neon light radiates an adequate amount of energy in the first (visible) range, almost none at all in the second and third ranges and a very large proportion in the last range (above 3 μ). A glowlamp, on the other hand, which in the visible spectrum gives the same amount of radiation energy as the neon tube, radiates light rays principally in the two ranges of 0.8 to 1.3 and up to 3 μ. It is, moreover, probable, although not yet confirmed by experiments, that the infra-red radiation in the range from 0.8 to 3 μ causes more "legginess" in plants than the very long wave radiation 3 μ. For the latter radiation is already radiated to a considerable extent by the heating arrangements provided in greenhouses and living rooms.



(a) (b)

Fig. 2. Infra-red radiation in neon light (*a*) and in glowlamp light (*b*). The infra-red range is divided into three fairly arbitrary parts. The ratio of visible to infra-red radiation is much less favourable with the glowlamp than with the neon tube. At the same time radiation between 0.8 and 3 μ, which probably is mainly responsible for the unwanted "legginess" of plants, is almost completely absent in the neon light, whilst it constitutes the greater part of radiation from the glowlamp.

The points outlined above have been confirmed by a large number of experiments on a wide variety of plants, in which the neon light was found exceptionally suitable for plant irradiation. In *figs. 3* to *6* a few of the results arrived at in these experiments are reproduced. The general observation may be made that apart from more rapid growth larger leaves are also formed, which owing to the greater amount of chlorophyll formed are coloured a dark green [4]), the stems are thicker, the roots are stronger, and frequently the formation of fruit and blooms is also much promoted.

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[2]) J. W. M. **Roodenburg**: Kunstlichtcultuur, October, 1930 and December, 1932. Meded. Landbouwhoogeschool Wageningen, vol. **34**, No. 8 and vol. **36**, No. 2. (Published by R. Veenman, Wageningen.)

[3]) In some cases it is mainly a question of rapid growth, as in the germination of seeds and bulb culture, etc. No carbohydrates need be formed in these instances, their formation taking place at the cost of reserve bodies which have been accumulated in the bulb. With these plants, growth may be equally well promoted merely by increasing the temperature; "light" is of no specific value here.

Dosage of irradiation

Similar to the procedure dictated in irradiation treatment for medical purposes, the application of the correct dosage is also a most important factor in the irradiation of plants if successful results are to be obtained. The correct dosage can also be established by actual experiments, and is determined by two factors: The radiation intensity to be used and the time during which the plants are exposed to irradiation. Important experimental data have already been collected regarding this question, particularly by the Agricultural College at Wageningen. It is evident that in these experiments the "efficiency" of irradiation has also had to be given consideration in view of the practical adoption of the method by market growers: The costs of irradiation must be in reasonable proportion to the extra return which well-developed plants will fetch.

As regards the requisite intensity of irradiation, the experiments have shown that with the majority of plants very good results can be obtained with an illumination intensity of 500 to 1000 lux. For purposes of comparison it may be stated that the mean illumination on a December day at about 3 o'clock in the afternoon is roughly 3000 lux and during the evening on a sufficiently illuminated desk about 200 lux.

Turning to the irradiation times, it is possible to regulate the "light diet" of the plants in a variety of ways. Consideration must be given to the stage of growth at which the plants are irradiated, furthermore for how many weeks or months irradiation is to be applied and how many hours each night. In general an irradiation period of 8 hours nightly is recommended, e.g. from 10 p.m. to 6 a.m. It does not lie within the scope of this article to set forth full instructions for irradiating plants, such as have been worked out on the basis of the research carried out at Wageningen referred to above, particularly as the instructions vary according to the genus of the plants.

The irradiation of Star of Bethlehem (Campanula isophylla) may, however, serve as an example. This plant, which is slipped and potted in spring and is disbudded as much as possible during the summer, is usually transferred to the forcing house about the first of September. About the middle of November irradiation with neon light is commenced (at a forcing house temperature of 15 °C.). During the first few weeks little result is to be seen, although the irradiated plants very soon acquire a fine dark-green colour. During December the growth of the plants is rapid and large leaves and stout stems are formed. At the end of January, when the plants have borne a host of buds, irradiation can be terminated. Irradiation is therefore only applied during the budding period. As early as the beginning of February the first buds will open on the irradiated plants (see the photograph in fig. 3).

Plant irradiation equipment. Neon tubes

At the time neon lights were introduced for the irradiation of plants, they had already been employed for several years for luminous advertisements. The neon light sources used for these purposes consisted of a long glass tube, into the ends of which two iron electrodes were fused, and containing a neon filling at a pressure of approx. 10 mm. They were run on high tension (e.g. 3000 volts) and emitted a comparatively small luminous flux per metre of tube length (160 lumens per m). The use of high tension in damp forcing houses for the irradiation of plants met with serious objection as well as the low brightness of the high-tension tubes. To obtain the requisite illumination of at least 500 lux

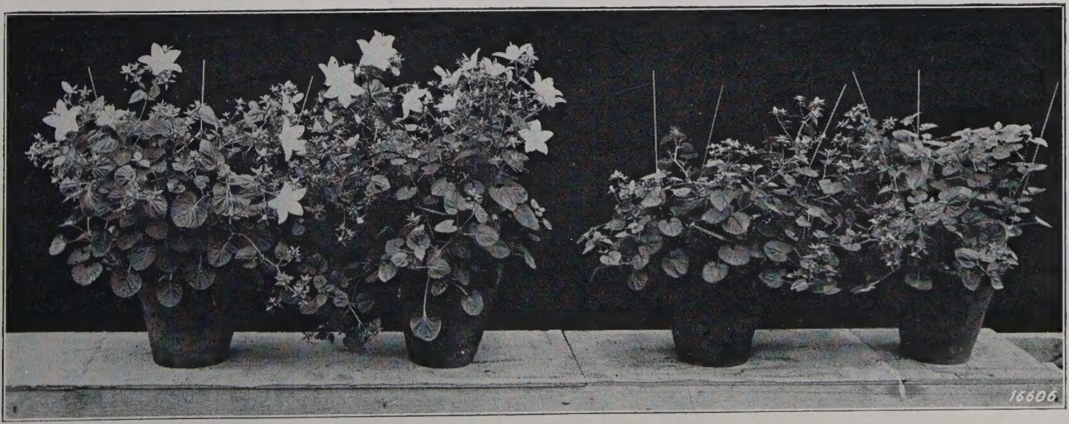

Fig. 3. Star of Bethlehem (Campanula isophylla). Picture taken on February 5, 1934. Left: Irradiated with neon light, 600 lux, each night from 10 p.m. to 6 a.m. from November 2, 1933, to January 25, 1934. Right: plants non-irradiated.

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[4]) This result is frequently observed after only a few nights' irradiation.

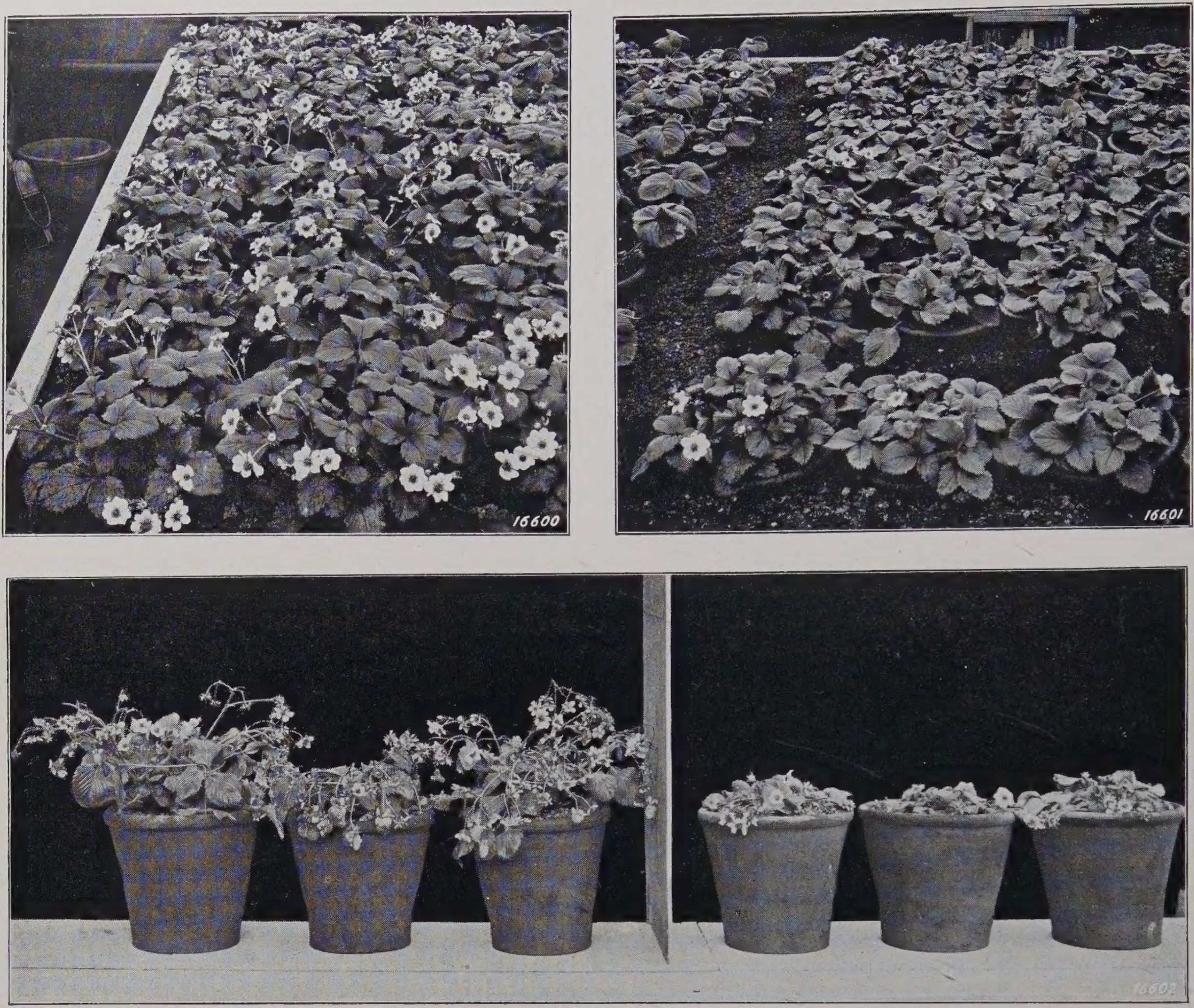

Fig. 4. Strawberry, var. "Deutsch Evern." Potted in the open, July 19, 1935; transferred to forcing house October 2.
a) Picture taken on December 7, 1935. Left: Irradiated with neon light, approx. 450 lux, nightly 10 p.m. to 6 a.m. Right: Non-irradiated plants.
b) Picture taken February 28, 1936 (towards the end of the crop). Left: Irradiated as at (a). Right: Non-irradiated plants.

a tube already about 5 m long was required for 1 sq. m of radiation surface.

The illumination intensity could only be increased at that time by raising the current intensity, but with the then normal pressure (10 mm) of the neon filling this had a very adverse effect on the efficiency and the life of the tubes. A satisfactory efficiency could only be achieved with a pressure of 1 mm and below, or by increasing the current density in the tubes ten times. This lower pressure, however, led to a pronounced disintegration of the iron electrodes due to ionic bombardment resulting from the high voltage drop at the cathode in this range (approx. 300 volts); the life of a low-pressure neon tube was thus reduced to a few hours. Amelioration was afforded by the use of hot cathodes, which owing to their electronic emission reduced the cathode fall to a few volts and enabled the tubes to be run on low-tension. Modern gas-discharge lamps for highway lighting are also constructed on this principle. Compact high-power units are thus obtained, operating with currents of a few amperes instead of for instance 25 milliamps in the case of high-tension tubes. A selection of early and

Table I. Dimensions and Data of a High-tension Neon Tube (*H*) and Three Low-Tension Neon Tubes (Type Nos. 4307, 4309, 4311).

Tube	Running voltage volts	Overall diameter mm	Length of light column m	Tube current amps	Consumption watts	Light output lumens	Gross light yield lumens per watt
H		13—14	2	0.025	36	320	9
4307	380	40—43	1.5	3.0	500	8750	17.5*)
4309	220	45—48	1	4.5	450	6300	14
4311	220	16—18	0.35	0.95	90	1200	14

*) The light yield of the neon column after substracting the losses in the input unit and at the electrodes is in this case 26.5 lumens per watt.

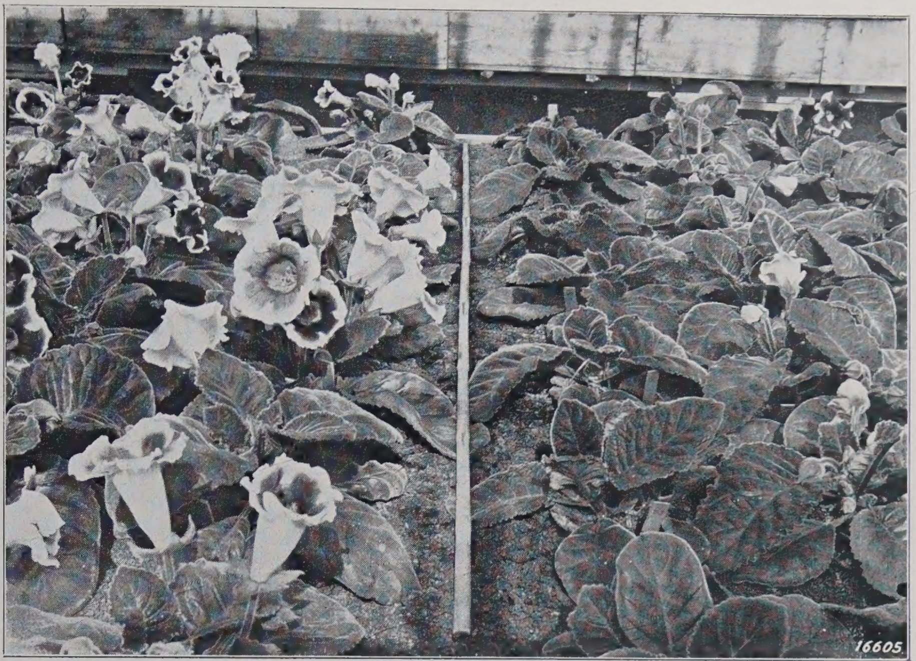

Fig. 5. Gloxinia, var. Kaiser Friedrich. Bulbs planted Nov. 11, 1932. Picture taken on April 3, 1933, i.e. one month after end of irradiation period. Left: Irradiated with neon light, approx. 800 lux, 8 hrs. nightly, until the end of February. Right: Non-irradiated plants.

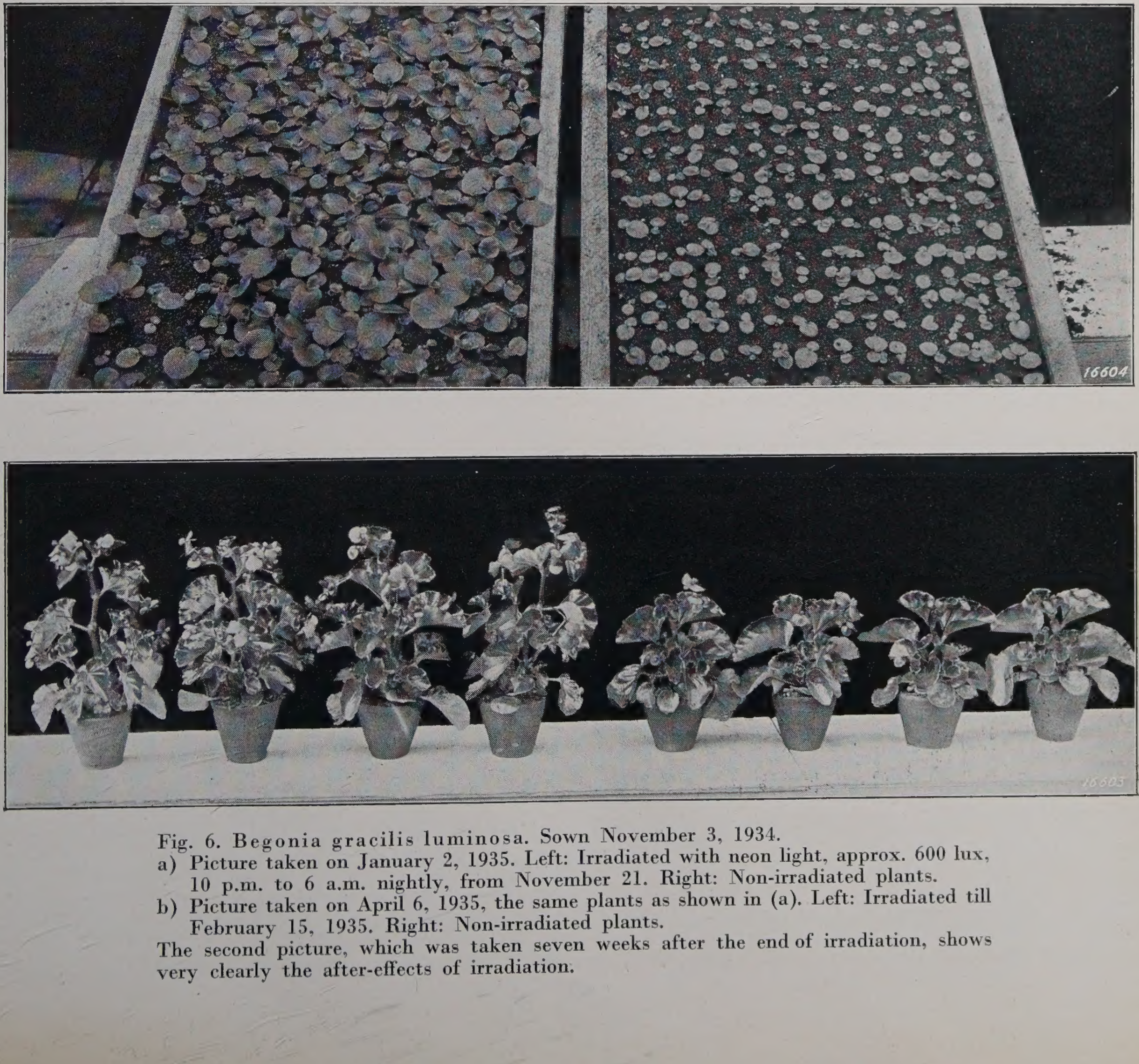

Fig. 6. Begonia gracilis luminosa. Sown November 3, 1934.

a) Picture taken on January 2, 1935. Left: Irradiated with neon light, approx. 600 lux, 10 p.m. to 6 a.m. nightly, from November 21. Right: Non-irradiated plants.
b) Picture taken on April 6, 1935, the same plants as shown in (a). Left: Irradiated till February 15, 1935. Right: Non-irradiated plants.

The second picture, which was taken seven weeks after the end of irradiation, shows very clearly the after-effects of irradiation.

modern types of tube are shown in *fig. 7*. A summary of the dimensions, applications and light outputs of these tubes is given in *Table I*.

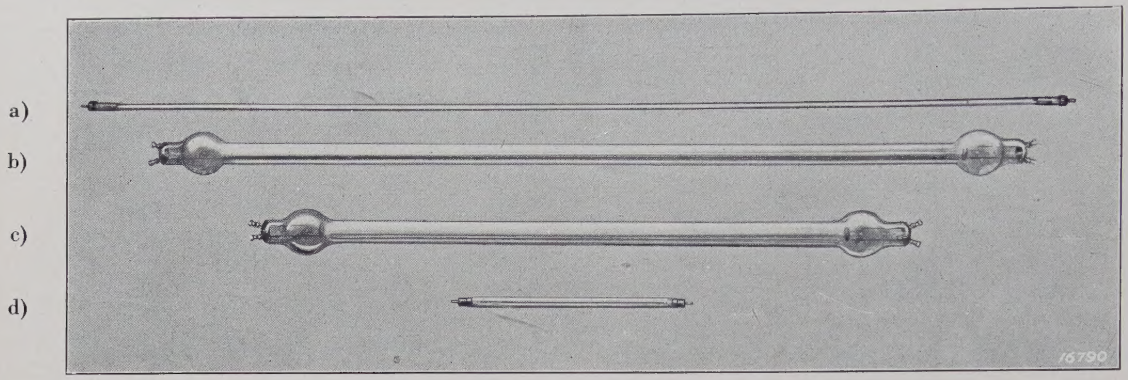

Fig. 7. Some early high-tension neon tubes (*a*) and various modern low-tension neon tubes (*b* to *d*). The electrical and illumination characteristics of these tubes are collated in Table I. Tube (*b*) emits practically 30 times as much light as (*a*) with approximately double the light yield; the small tube (*d*) gives almost four times the light obtained from (*a*).

The hot cathode is that component of the tube which ultimately determines the life of the tube, since the emitting substance (barium-strontium oxide) on the heated coil is steadily consumed. During the burning of the lamp the cathode suffers practically no disintegration at all and the light output of the tube remains uniform. Only after 2000 running hours does the consumption of the radiating substance become noticeable, the voltage-drop at the cathode increases, the cathode commences to be atomised, and in its neighbourhood a black deposit forms on the glass wall [5]), which adsorbs gas, as a result of which the cathode voltage-drop increases considerably until it becomes impossible to run the tube off the mains voltage and the tube must be replaced. The long life of 2000 running hours of the tube is due, *inter alia*, to the fact that in front of each cathode a plate is located (see fig. 7) which in the positive phase of the alternating voltage serves as anode and in this way protects the heated coil from excessive heating during the anode phase.

Circuit details and construction of plant irradiators

The neon tubes with hot cathodes are connected directly to 220 or 380 volts mains supply through a series-connected choke coil. In contrast to high-tension tubes special provision must be made here for starting up the tube, since the running voltage is too low to initiate the first electric discharge through the low-pressure neon gas. The extra-tension impulse which is obtained at the terminals of the series-connected choke on shorting the neon tube is utilised for this purpose. After the first discharge has taken place adequate residual ionisation is retained in the tube for re-ignition to be regularly obtained with a 50-cycle A.C. on reversing the polarity, even with a voltage which is too low for initiating the first discharge.

The circuit details of the large plant irradiators (types 4308, 4310 with tubes 4307, 4309) which have been designed for market growers, are shown in *fig. 8*. *T* is the heating transformer for the heated coils *K* which are run on 2 volts and 18 amps. *S* is the series choke coil. The heating coil *R* and the bimetallic strip *B* constitute a slow-acting relay, which connects up the initially-shorted tube *L* only after the coils *K* have become sufficiently heated. The tube is thus started up automatically by the slow-acting relay. If the first attempt at starting up fails owing to the phase of the supply being temporarily unfavourable at the instant the relay operates, the starting procedure is immediately repeated. The condenser *C* connected in parallel with the tube facilitates re-ignition, thus reducing

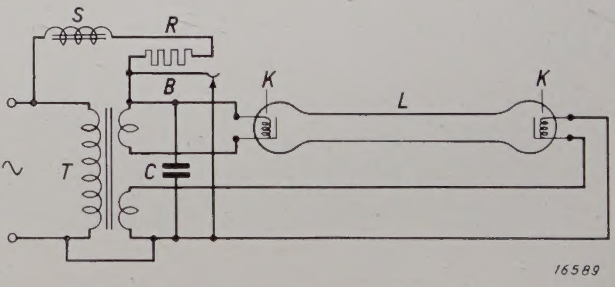

Fig. 8. Circuit details of the plant irradiator 4308 and 4310. The tube *L* is connected to the A.C. mains through a series-connected choking coil *S*. A bimetallic slow-acting relay *R* and *B* control signition. The cathodes *K* are heated through their own heating transformer *T*.

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[5] The black deposit is always restricted to the neighbourhood of the cathodes; the whole tube is never covered with a black deposit.

the mains voltage required and at the same time suppressing radio interference.

For small-scale operations and to meet the requirements of amateur horticulturists for conservatories and indoor use, a lower-power irradiator (rated for 90 watts) has been designed of which circuit details are given in *fig. 9*. By omitting the automatic starting device the circuit has been much simplified, whilst it has also been found possible to dispense with a heating current for the cathodes. When the cathodes have been once raised to the requisite temperature at the beginning of the discharge, they are kept suitably hot by the discharge itself. By introducing a special circuit the series choke coil is used as a heating transformer for heating the cathodes at the start of the discharge: After connecting the irradiator to the mains the two-pole switch *S* is pushed in, so that the choke now acts as an auto-transformer and the hot cathodes heat up. After releasing the switch the tube fires and the original circuit is re-established.

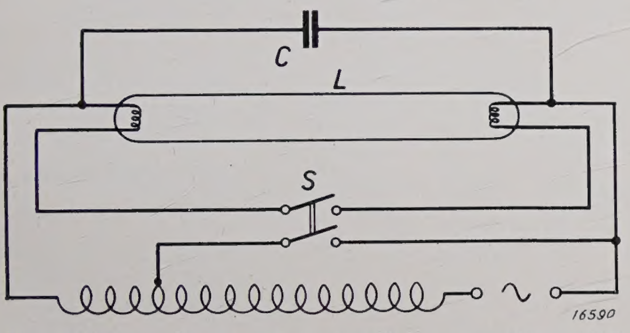

Fig. 9. Circuit diagram of the small plant irradiator 4312. By dispensing with the automatic ignition device the circuit has been much simplified; the choke coil also acts as a heating transformer.

The light-yield of this small tube is 14 lumens per watt (taking into consideration all losses); it has a life of 1000 running hours.

Installation of irradiation units

The neon tubes are mounted in reflectors, which considerably increase the efficiency of irradiation. These reflectors are flat and fairly small, so as not to take up too much space in the usually low forcing and greenhouses and particularly so that they do not cast a wide shadow during the day. The live ends of the tube are protected in the reflectors. The large irradiation units 4308 and 4310 (see *fig. 10*) are connected up through cables to a watertight cast-iron box containing the transformer, choking coil and relay. In the case of the small irradiator 4312 the input unit (choke, condenser and switch) is incorporated with the tube in the radiator, thus making a very simple arrangement which can be directly connected to a 220-volt A.C. mains plug (*fig. 11*). With this unit an area of 10 sq. ft. can be adequately irradiated from a distance of 20 to 24 in.; the larger irradiator 4308 is sufficient for irradiating an area of about 100 sq. ft. The large units are suspended above the plants at a height of 3 to 5 ft. When suspending a series of irradiators in a forcing house a space equal to the length of the irradiator is usually left between consecutive units, this arrangement permitting an efficient and comparatively uniform irradiation of the plants.

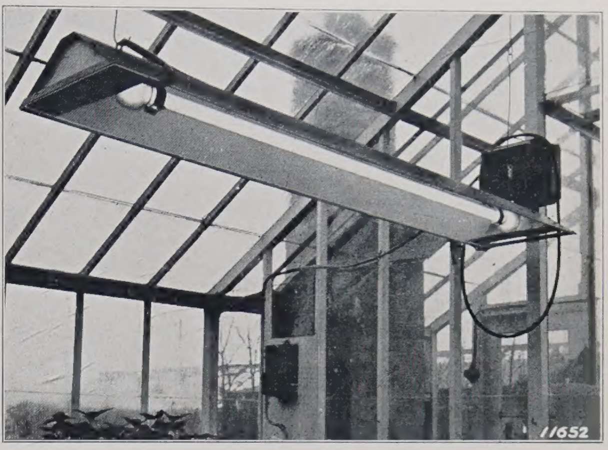

Fig. 10. The large plant irradiator 4310 installed for use. The input unit (*T*, *B*, *R*, *C* and *S* in fig. 8) is enclosed in the watertight cast-iron box on the right, to which the tubes mounted in the reflector are connected by a cable.

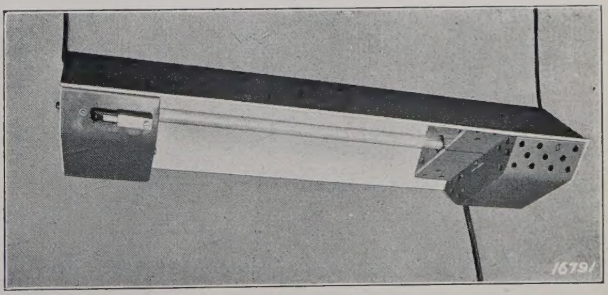

Fig. 11. The small plant irradiator 4312. The input unit is here incorporated with the tube in the reflector, thus giving a very simple arrangement.

THE DISK TEST AS A RAPID METHOD FOR ESTIMATING THE MACHINABILITY OF STEEL

(Continued from p. 187)

In the first part of this paper the general procedure adopted in the Taylor test and the disk test was discussed and the relation between these two methods of test analysed. In the present section the experiments carried out here and the results arrived at are reviewed.

General Experimental Details

Materials Used. To facilitate a discussion of the test made, full details of all types of steel used in these investigations are given in *Table I*.

Cooling agents. In accordance with the experimental work carried out by other investigators no cooling agents or lubricants were used in the present work. Although the absence of a cooling agent considerably reduces the cutting efficiency of cutting tools, the advantage gained is that the experiments are more closely reproducible.

Shapes of Cutting Tools Used. In his experiments Brandsma employed tools with straight sides, and in later work adopted knife-edge cutters of the type already illustrated in figs. 1 and 3. The shape of these tools is shown more clearly in *figs. 6* and *7*. In fig. 6 the sizes of all angles are given. It is seen from the last but one column in Table I that the cutting angle was not taken the same for all steels; in fact the most suitable angle for each particular steel was selected. The only difference between the cutting tools used in the disk tests (see figs. 3 and 7) and those used in the Taylor tests (see fig. 1) was that in the former the back of the tool was ground down so that the cutting edge alone was in contact with the test disk. The cutting properties of the steels are probably very little influenced by this modification.

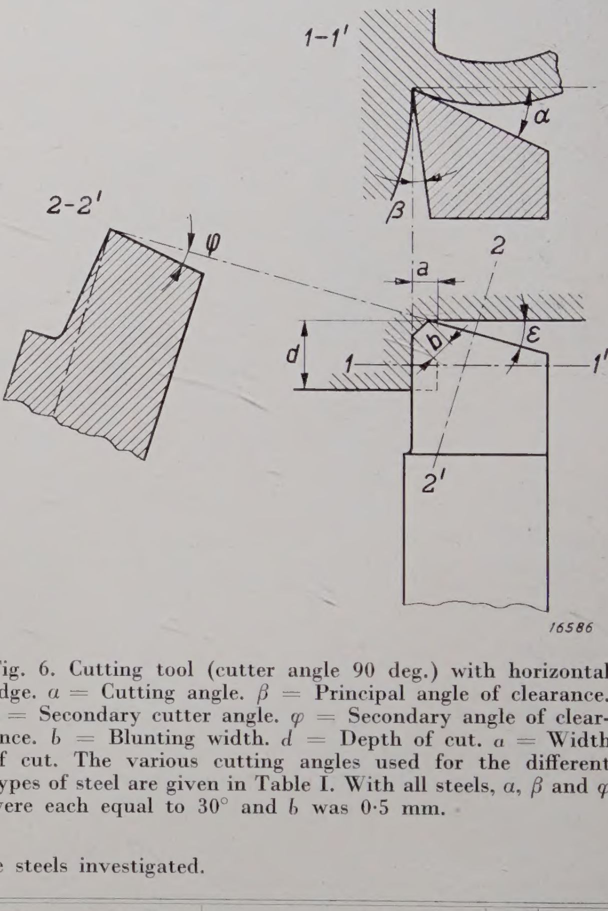

Fig. 6. Cutting tool (cutter angle 90 deg.) with horizontal edge. α = Cutting angle. β = Principal angle of clearance. ε = Secondary cutter angle. φ = Secondary angle of clearance. b = Blunting width. d = Depth of cut. a = Width of cut. The various cutting angles used for the different types of steel are given in Table I. With all steels, α, β and φ were each equal to 30° and b was 0·5 mm.

Table I. Survey of all the steels investigated.

Type	Approx. percentage composition of components other than Fe											State in which used	Angle of cut	Brinnell hardness (10/3000/30)
	Carbon	Silicon	Phosphorus	Sulphur	Vanadium	Chromium	Manganese	Cobalt	Nickel	Molybdenum	Tungsten			
Carbon Steel I	0.08	<0.5	0.08	0.15	—	—	<0.8	—	—	—	—	Forged	25°	116
Carbon Steel II	0.15	<0.35	<0.04	<0.04	—	—	<0.4	—	—	—	—	"Normalised"	25°	121
Carbon Steel III	0.45	<0.35	<0.03	<0.03	—	—	<0.8	—	—	—	—	"Normalised"	20°	174
Chromium steel	0.12	<0.35	<0.03	<0.03	—	0.4	<0.4	—	—	—	—	Soft annealed	25°	107
Nickel-chromium steel I	0.14	<0.35	<0.03	<0.03	—	0.75	<0.5	—	3.5	—	—	Soft annealed	20°	175
Nickel-chromium steel II	0.30	<0.35	<0.03	<0.03	—	1.0	0.6	—	3.5	0.4	—	Heat-refined	15°	311
Nickel-chromium steel III	0.35	<0.35	<0.03	<0.03	—	1.2	<0.6	—	4.5	—	—	Soft-annealed	15°	263
Tool steel I	1.1	0.3	<0.03	<0.03	—	1.0	1.0	—	—	—	1.0	Soft-annealed	15°	216
Tool steel II	2.2	0.6	<0.03	<0.03	—	1.2	0.25	—	—	—	—	Soft-annealed	15°	241
Cobalt high-speed steel	0.7	<0.35			1.5	5	<0.25	16	—	—	20	Hardened and twice annealed		
Vanadium high-speed steel	1.2				3.5	5		—	—	0.7	15	Hardened as delivered		

Lathes Used. The first disk tests were carried out on a lathe with a maximum speed of 600 r.p.m.

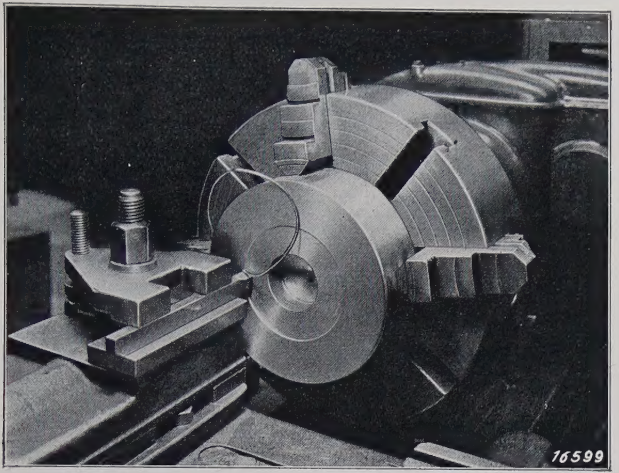

Fig. 7. View of lathe as used for carrying out a disk test.

and driven by a 4 h.p. motor. Subsequently these tests were carried out on the same lathe as used for the Taylor tests. This lathe had a maximum speed of 1500 r.p.m. and was driven by a variable-speed 7.5 h.p. D.C. motor. The cutting speed was kept as constant as possible during the tests with the aid of a tachometer.

Disk Test for Examining the Heat Treatment of High-Speed Steels

The high-cobalt high-speed steel shown in Table I was used in these tests, and tools ground from square bars of 12-mm side. After annealing, the tools were reheated once or twice. Very important factors in heat treatment are the annealing temperature, the rate of cooling and the number of times re-heating is applied.

In investigating the influence of these factors, all cutters were tested on disks of a very homogeneous and pure plain carbon steel which, apart from a somewhat higher manganese content, was similar to carbon steel II shown in Table I. The width of cut was 0.125 mm and the depth of cut 1.0 mm in all cases.

Effect of the Annealing Temperature. In those experiments designed to establish the influence of the annealing temperature, all tools were reheated twice. This characteristic twofold reheating with intermediate cooling is particularly recommended for high-cobalt high-speed steels in order to obtain a high hardness value (cf. Table II).

The results obtained in disk tests carried out on two cutting tools to estimate the effect of the annealing temperature are given in *Table II*, which shows, firstly, that the tests are satisfactorily reproducible and, secondly, that the maximum cutting speed v_m is the greater the higher the temperature of annealing.

Table II. Maximum cutting speed in disk test (v_m in m per min) in relation to the annealing temperature of the cutting tool in deg. C.

Annealing temperature	v_m	v_m after re-grinding	Average value of v_m
1280	220 211	217 221	217
1300	224 227	223 223	224
1320	225 225	243 234	232
1340	244 241	258 246	247

Influence of the Number of Re-Heatings. The results of tests performed to examine this question are collated in *Table III*, which also gives the corresponding "Rockwell hardness on the C-scale" in column *H*. It should be noted that twofold annealing results in an improvement only at the higher annealing temperatures, whilst on the other hand a third annealing process has a marked adverse effect on the cutting properties of the steels.

It may be quite definitely concluded from the table that the hardness is in many cases an unreliable measure of the cutting properties of a steel. On twofold annealing a greater hardness corresponds to better cutting properties as measured in the disk test, in other words a greater hardness is equivalent to a higher cutting speed v_m. On comparing the steels which have been annealed twice and three times, it should follow from the hardness values that treble annealing would be more advantageous, although disk tests show that the cutting properties of the steel are then less satisfactory than after a single annealing process.

Effect of the Rate of Cooling in Annealing. In the case of high-cobalt high-speed steels very

Table III. Rockwell hardness on scale C (*H*), and maximum cutting speed in the disk test (v_m in m per min) in relation to the annealing temperature in deg. C on reheating 1 to 3 times.

Annealing temperature	After no reheating	After reheating once		After reheating twice		After reheating three times	
	H	*H*	v_m	*H*	v_m	*H*	v_m
1280	60	63.5	211	62.5	209	62.5	182
1300	55.5	61	221	64	217	63	185
1320	52.5	60.5	214	65	220	63.5	190
1340	51	59.5	218	66	241	65.5	230

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[8] W. F. Brandsma, Metaalbewerking **2**, 541, 1936.

rapid cooling is not desirable in view of the risk of hardness cracks appearing and of the premature crumbling of the cutting edge on the lathe. The effect of cooling was studied by cooling in compressed air, slower cooling in the fairly quiescent hot air of a furnace and still slower cooling in a very highly-insulating kieselguhr. As it was intended to detect particularly any brittleness developing, a groove 13 mm wide was cut radially in the disk in such a manner, that the cutting was interrupted once during each revolution. The results of these experiments are given in *Table IV*, where it is shown that the cutting ability increases with the rate of cooling and that it is barely affected by periodic interruption. Whether the brittleness can be evaluated in this way, therefore appears very doubtful, although some information on this point was furnished by a number of works tests and a metallographic examination of the structure. On the basis of these experiments and the results of the disk tests described above, the optimum heat treatment required for the steels was established.

Table IV. Rockwell hardness on scale C (H), and maximum cutting speed in the disk test (v_m in m per min) in relation to the annealing temperature in deg. C. and the rate of cooling during annealing.

Annealing temperature	Cooling in	Rate of cooling	H	v_m	v_m after regrinding	Average value of v_m
1300	Compressed air	Fairly slow	63.5	*)	214	214
	Furnace	Slow	64	199	200	200
	Kieselguhr	Very slow	60.5	185	185	185
1320	Compressed air	Fairly slow	64.5	223	237	230
	Furnace	Slow	63.5	220	207	213
	Kieselguhr	Very slow	62	196	199	197
1340	Furnace	Slow	64	226	220	223
	Kieselguhr	Very slow	63.5	217	157	187

*) Gradually became useless.

Disk Test for Testing and Classifying Steels according to their Machinability [9])

To determine whether the results obtained in disk tests are in concordance with those found by the Taylor test, a large number of experiments were carried out with the first nine steels enumerated in Table I. In these tests those cutting tools were used which had been found best suited for both the Taylor and disk tests, i.e. the exact instant at which the edge crumbled could be readily observed in each case, this not being always the case with other forms of cutting tools. All steels used in the investigation described below were made from high-speed vanadium steel (delivered hardened) given in Table I.

In both the Taylor and the disk tests the depth of cut d and the width of cut a were 1.00 and 0.26 mm respectively. With each of the steels studied, the material for both the Taylor and the disk tests was taken from the same bar; only with tool steel II was this not possible as the available bar diameter for carrying out the disk test was too small. But disks of sufficiently large diameter were available. The diameter D_0 of the hole in the disc was again 50 mm in all tests.

In all Taylor tests, always the same three cutting tools were used in a continuous series of measurements for plotting the complete v-T curve with all types of steel [10]), so that the final results given below

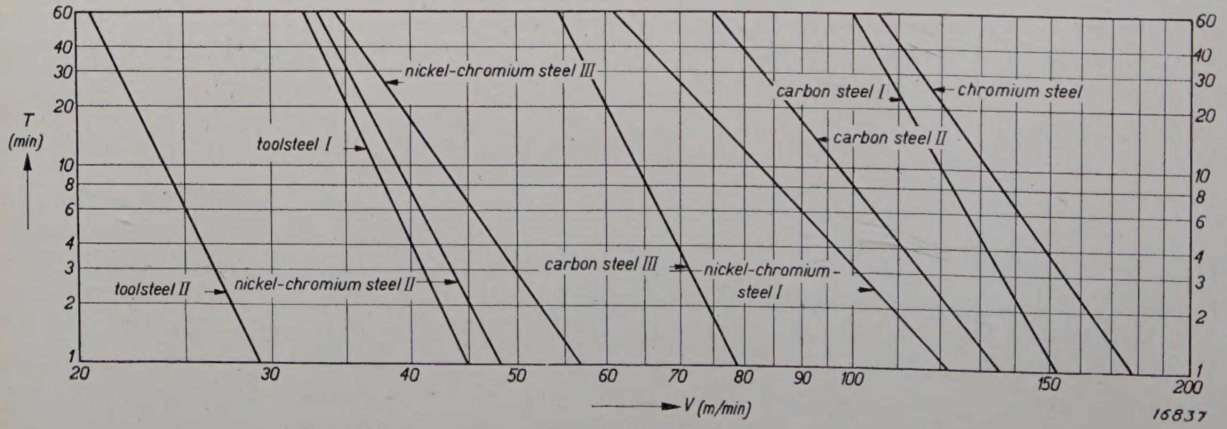

Fig. 8. Results of Taylor tests with various types of steel. For each steel the durability periods T for several different cutting speeds v were determined and plotted in a double-logarithmic diagram.

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[9]) J. R. J. van Dongen and J. G. C. Stegwee, Metaalbewerking **3**, 1 and 49, 1936. Special attention is called to the second part of this paper, which gives a comprehensive summary of all quantitative measurements.

[10]) In other words, after plotting one point of the v-T curve the worn cutting tool was reground before plotting the next point, and after the whole v-T curve had been plotted the same process was repeated with each of the other two tools.

may be regarded as the averages of three complete sets of tests. Three different tools were similarly used in the disk tests and with each tool the N-v_m curves for all the steels were plotted. Here again the final result given is a mean of three complete series of tests.

The results obtained in the Taylor tests are shown graphically in *fig. 8* and those in the disk tests in *fig. 9*. The principal values derived from the two graphs being a comparison between the two tests are collated in *Table V.*

Table V. Results of Taylor and disk tests (v_m in m per min) in relation to the cutting speed.

Material	Taylor tests					Disk tests
	N	C *)	v_1 *)	v_{30}	v_{60}	v_m(100)
Chromium steel	8	178	178	115	105	282
Carbon steel I	10	152	152	107	100	243
Carbon steel II	7	135	135	87	75	225
Nickel-chromium steel I	6	122	122	68	61	167
Carbon steel III	11	79	79	57	54	112
Nickel-chromium steel III	8	57	57	37	34	83
Nickel-chromium steel II	11	48	48	35	33	64
Tool steel I	12	45	45	34	32	62
Tool steel II	11.5	29	29	22	20.5	33.5

*) The values of C and v_1 are in agreement, although the dimensions of these magnitudes are different.

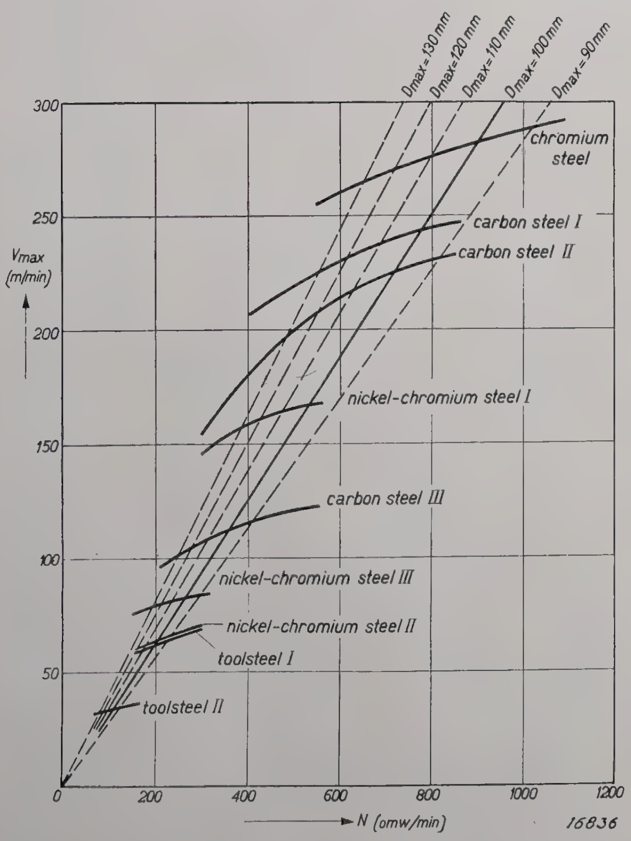

Fig. 9. Results of disk tests with various types of steel. For each steel the cutting speed v_m at the instant of collapse of the tool was determined for different lathe-speeds.

In addition, the cutting speed v_{30} corresponding to a durability of 30 min was calculated from the results of the disk tests, using equation (5). In this calculation n was obtained directly from the results of Taylor tests, since the lathe speed N in the disk tests was altered by too small an amount for each type of steel to allow n to be calculated therefrom with sufficient accuracy. The values of v_{30} calculated from equation (5) are collated in *Table VI* and fig. 5 together with those of v_{30} (see also table V) read from fig. 8. The agreement is seen to be very satisfactory. The greatest difference between the calculated and the measured values is 13 per cent, the average difference being only 7 per cent, which is not very serious when it is remembered that in Taylor tests the values of v_{30} cannot be determined with an accuracy greater than about 5 per cent.

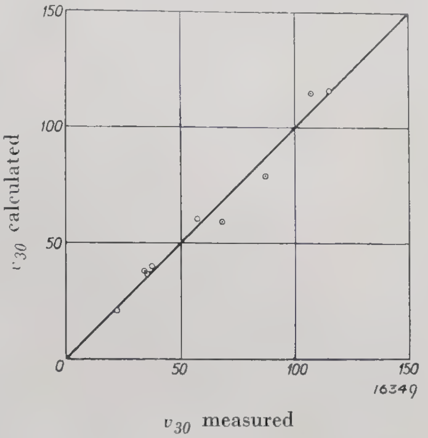

Fig. 5. Calculated values of v_{30} plotted against measured values.

Table VI. Survey of values of v_{30} as measured in Taylor tests and as calculated from disk tests (both in m per min).

Material	v_{30} measured in Taylor tests	v_{30} calculated from disk tests
Chromium-steel	115	116
Carbon steel I	107	115
Carbon steel II	87	79
Nickel-chromium steel I	68	59
Carbon steel II	57	60.5
Nickel-chromium steel III	37	40
Nickel-chromium steel II	35	37
Tool steel I	34	38
Tool steel II	22	21

As regards the possible routine testing of structural steels for their workability and machinability, it must be remembered that in the present article only the turning of small-sectional chips has been discussed and no reference has been made to rough turning, boring, planing, milling and grinding, etc. In practice it is essential to study these methods of working too. Since for round bars turning is the most common and most important operation, it should be possible to obtain satisfactory data of the machinability of various materials with the disk test by employing widely-different sections of chips.

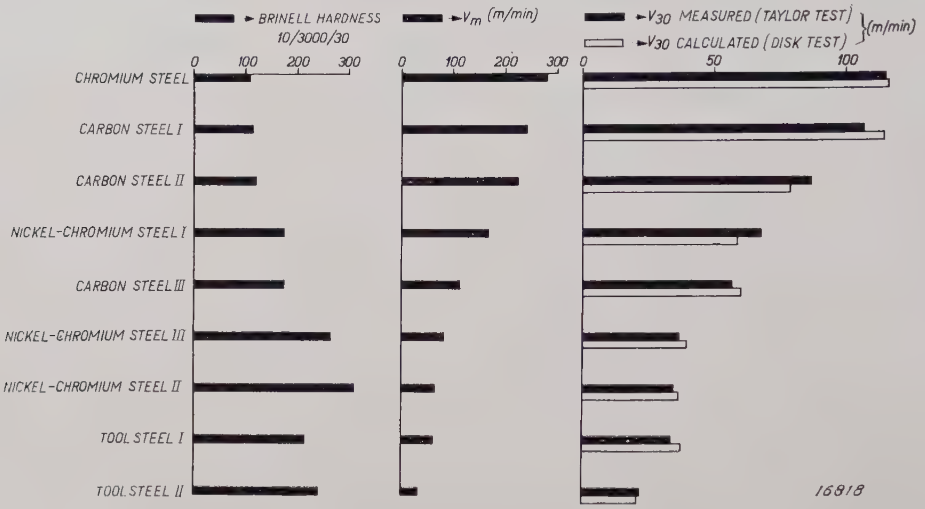

Fig. 10. Various criteria of machinability compared for a number of different steels: The Brinell hardness (10/3000/30), the maximum speed v_m measured in the disk test, the value of v_{30} calculated from the disk test, and the value of v_{30} measured in the Taylor test. It is seen that the two latter are in very good agreement. The Taylor test gives decidedly the most direct measure of the machinability. The results of the disk test, either recalculated or not, i.e. v_{30}(cal.) or v_m, lead to the same conclusion. On the other hand the Brinell hardness would lead to an entirely wrong conclusion.

Yet, before the disk test can be adapted to a routine test, much additional research has still to be carried out and in particular the relation between the Taylor test and the disk test should be investigated experimentally with greater accuracy and over a wider range. That an investigation over these lines is worth while is evident from a consideration of the advantages which the disk test offers over the Taylor test. It is sufficient to indicate but a few here and to emphasize the marked potential importance of the disk test for routine daily tests: practically every lathe can be readily adapted for carrying out the disk test; there is also less danger of the cutting tool crumbling owing to slag inclusions; the duration of a test is short and moreover little material is required.

Compiled by P. CLAUSING.

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[11] These figures give in order the diameter of the ball in mm, the pressure in kg and the time in seconds employed in measuring the hardness with the Brinnell apparatus.

AUTOMATIC STARTING RESISTANCES
("STARTO" TUBES)

By P. C. VAN DER WILLIGEN.

Summary. The starting impulse obtained with many electrical consumers can be reduced or suppressed altogether by series connection of a resistance with a negative temperature coefficient (high resistance when cold and low resistance when hot). This principle has been employed in the "Starto" starting tubes. The construction and characteristics of these tubes are described in this article, and their application to typical cases, such as for starting motors, for the gradual switching-on of lighting circuits, and for delayed circuit closing, etc., are discussed by reference to concrete examples.

Introduction

On switching on large electrical machinery heavy current impulses are frequently obtained, which are due to the fact that the working current absorbed by a motor is not limited by the resistance of the armature windings, but by the reverse voltage induced in the rotor. At the instant the motor is switched on, no counter-voltage is produced if the rotor does not immediately start to move; in this case the current may become several times greater than the normal working current. It thus usually becomes necessary to protect the armature windings against overheating when starting.

A starting rheostat is generally connected in series to the windings to prevent this overheating, this resistance being gradually reduced either by hand or automatically as the speed of the motor increases to its normal value during the starting period. At the outset the resistance must have a high value which gradually drops to a low end value. This type of resistance variation is found in semi-conductors (metalloids, metallic compounds, etc.) whose electrical resistance has a negative temperature coefficient, in other words the electrical resistance decreases as the temperature rises. When a semi-conductor of this type is connected in series with the consumer, the starting current is limited by its resistance when cold. During starting, the temperature of the resistance is raised by the passage of current and the resistance value thus gradually drops to a much lower final value.

The starting tubes which Philips are marketing under the name of "Starto" tubes have been evolved on this principle; they can be used in all cases where it is desirable to procure a gradual increase in the current.

Before passing to a detailed description of the construction and characteristics of these starting tubes it should be pointed out that these tubes are the exact opposites of the hydrogen-filled iron-filament resistors which are used as regulators. In the latter, technical use is made of the pronounced positive temperature coefficient of the resistance of the iron; with a change in the voltage applied to the resistor the current passing may remain constant in certain circumstances [1]), cf. *fig. 1*, curve *A*. On the other hand the operation of the starting resistances depends on the marked negative temperature coefficient of the resistance (a specific semi-conductor), and in the current-voltage characteristic there is a range in which the voltage-drop across the terminals of the tube remains practically constant, when the current is altered [2]), cf. curve *B* in fig. 1. The two characteristics *A* and *B* are seen to be perpendicular to each other. As we shall see below, this property is not employed in the starting tubes during starting,

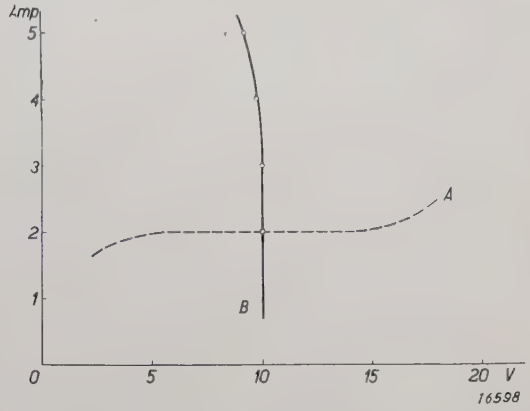

Fig. 1. Current-voltage characteristics: *A* - Iron filament resistor (Philips 1913). *B* - Starting tube ("Starto", 2-A type). The resistance of the first has a positive temperature coefficient and that of the second a negative coefficient. Each point on the curves corresponds to a condition of equilibrium.

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[1]) For if the current E/R tends to increase as a result of an increased voltage E, the temperature rise occurring at the same time causes an increase in the resistance R, so that E/R remains practically constant, at least over a certain part of the characteristic.

[2]) For if the voltage-drop IR tends to increase owing to a greater current I, the resistance R is reduced as a result of the temperature rise occurring at the same time, so that IR remains practically constant, at least over a certain part of the characteristic.

the operation of these tubes being in fact based on their inertia due to their marked thermal capacity.

Construction [3]) and characteristics

In "Starto" tubes, the semi-conductor used is a mixture of silicon and a ceramic binder. The resistance of silicon itself does not possess a pronounced negative temperature coefficient, but on "diluting" with a suitable binder this coefficient is considerably increased to give a very marked difference between the resistance when cold and when hot. A favorable circumstance is the fact, that these considerable differences appear with the addition of a small quantity of ceramic material (for instance 25 per cent).

The resistance material is used in the form of a rod enclosed in a glass tube filled with argon. The argon filling is required because the silicon of the rod reacts with oxygen and nitrogen.

To ensure that the characteristics of the starting resistance remain unchanged during service, the resistance material must not become too hot, i.e. it must not exceed a specific maximum in the end stage reached after starting up the current. *Figs. 2* and *3* illustrate "Starto" tubes designed for different maximum permissible currents from 1 to 100 amps. On full load the rod is raised to red heat and its temperature is then in the neighbourhood of 800 deg. C. With an overload there is the risk of altering the characteristics of the rod, which may even melt.

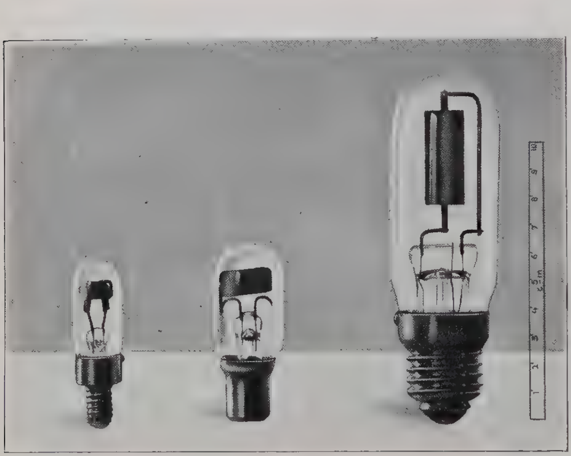


Fig. 2. "Starto" starting tubes for small currents, 1-amp, 3-amp and 6-amp types (the tubes shown here are all intended for 220 volts; tubes for 125 and 380 volts are also made).

Characteristic Curves

The lower half of *fig. 4* gives the current-resistance characteristic for starting tubes designed for 220 volts and 1.3 amp (fig. 2) and the upper half the

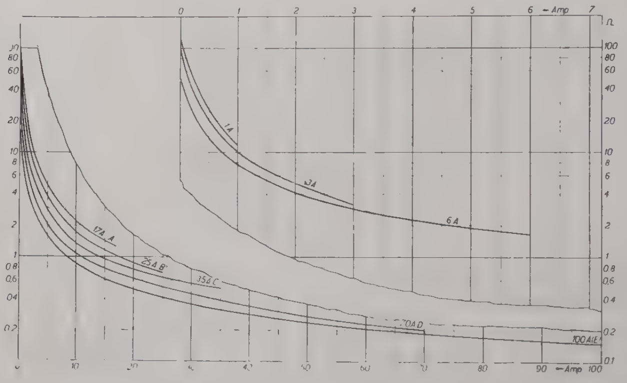
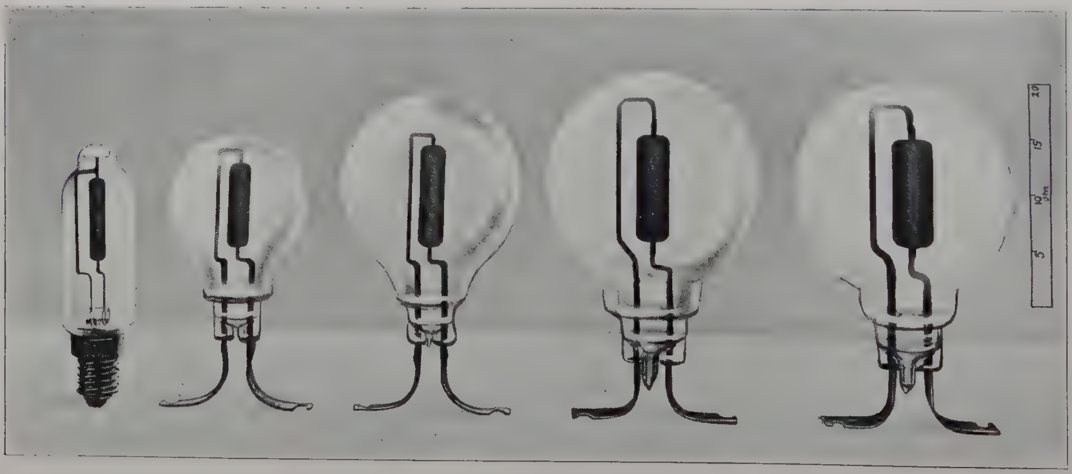


Fig. 4. Current-resistance characteristics of 220 volt starting tubes shown in fig-s 2 and 3. The ordinate (resistance in ohms) has been divided logarithmically in view of the large difference between the resistance when cold and when hot. Each curve is drawn up to the point of the maximum permissible working current for each tube.



A B C D E

Fig. 3. "Starto" starting tubes for higher currents: *A* (17 amps), *B* (25 amps), *C* (35 amps), *D* (55 amps) and *E* (100 amps).

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[3]) Assistance in the construction of the tubes described here was given by Messrs. Ploos van Amstel and De Schrevel.

corresponding curve for tubes designed for 220 volts and 17, 25, 35, 55 and 100 amps (fig. 3), denoted by the letters *A* to *E*. In both diagrams the ordinates have been divided logarithmically in view of the marked difference between the resistances when cold and when hot. Each curve has been drawn up to the point corresponding to the maximum permissible working current. Tubes *A* to *E* are manufactured for circuit voltages of 125, 220 and 380 volts; the only difference between an *A 125* and an *A 220* tube is in the length of the resistance material.

It follows from *fig. 4* that the final resistance will be the smaller, the greater the current for which the starting tube is designed. *Table I* gives these final resistances for tubes *A 220* to *E 220*.

Table I.

Type	Max. current in amps	Resistance in ohms	Voltage absorbed in volts
A 220	17	1.2	20
B 220	25	0.7	18
C 220	35	0.5	17
D 220	70	0.2	15
E 220	100	0.15	14

As may be seen, the voltage consumption in all types of tubes is about 12 volts, i.e. 5 per cent of the mains voltage. In the 125-volt tubes the average consumption is 8 per cent, and in the 380-volt tubes approximately 4 per cent [4]).

The resistances when cold are in the neighbourhood of 100 ohms with type *A 220* and of 15 ohms with type *E 220*; these values have been chosen such that the current on applying the full mains voltage is roughly $^1/_8$ of the maximum permissible current through the tube. By taking a suitable composition of resistance material the resistance when cold R_k can, however be altered within wide limits. Thus, a 3-amp tube can be made with a final resistance of 4 ohms and with $R_k = 200$ ohms, and also a tube for the same current rating with a final resistance of 5 ohms and with $R_k = 2000$ ohms[5]).

From the current-resistance characteristic the current-voltage characteristic can readily be deduced, being of the type given in fig. 1 for the 3-amp starting tube (curve *B*). The resistance varies almost in the inverse ratio of the current intensity over a very wide range of current values, so that in this range, as already indicated at the outset, the voltage consumed by the tube remains practically constant. With lower currents it is fairly difficult to trace the exact path of the curve; this is, however, of little importance since the points of this curve in fact relate only to equilibrium conditions. In practice an equilibrium is only reached when the current attains its final value, whilst during the starting period the resistance lags considerably behind the current owing to its marked inertia. As a result the voltage applied to the starting tube during starting (i.e. at low and increasing current intensities) is high and then drops to the final value of 10 volts as given in the characteristic curve.

Starting Time

The duration of the starting period, i.e. the time elapsing from the moment the switch is closed until the current reaches its maximum value, is determined by the time taken for an equilibrium to be reached between the heat supplied and the heat dissipated. The heat input is governed by the mains voltage, the resistance of the starting tube when cold R_k and the magnitude of the resistance in series with the starting tube. The heat dissipated depends on the shape and size of the tube. A consideration of the construction of the tube indicates that the starting time increases, the greater the resistance R_k when cold (small heat input) and the greater the mass and surface area of the starting resistance (slow temperature increase owing to greater thermal capacity and rapid dissipation of heat resulting from a larger surface). With a particular starting tube a variety of starting times can be obtained, depending on the mains voltage and the value of the resistance in series. With a specific low mains voltage (or a sufficiently high series resistance) the energy input of the starting tube can be made so small that an equilibrium between the heat input and the heat dissipated is already attained with a temperature increase of 30 to 40 deg. No starting is then obtained and the current retains its small initial value. Proper starting can still be achieved in this case by heating the starting resistance from an external source, e.g. with a resistance wire wound round the starting rod and connected in parallel with it (see also below, *fig. 9*). If the tube has been once heated up, then the current intensity and hence also the heat input of the tube is so much higher that, at a certain temperature at which the tube is at red heat, a second equilibrium between heat input and the excessive dissipation of heat is reached.

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[4]) In addition to the mains voltage R_k and the maximum permissible current, the resistance when cold is also marked on the glass bulb of the starting tube, e.g. 220 volts, 100 ohms/17 amps.

[5]) A rod of a semi-conductor served here as an incandescent body. As long as the rod absorbed little current, heating was furnished, immediately after switching on, by a resistance wire which is automatically cut out as soon as the rod becomes hot enough to conduct sufficient current to heat itself.

In nearly all applications of the starting tubes, the resistance of the series-connected consumer does not remain constant but steadily increases. When selecting a starting tube for a particular purpose, this point must also be considered in addition to those already referred to.

Cooling Period

The iron-filament resistor, which we have indicated as the opposite of the starting tube, is employed as a regulator in order to obtain a constant current in spite of a fluctuating voltage. The horizontal part of curve *A* in fig. 1 is therefore employed. A certain inertia in the resistor due to the time required for the temperature to change is, however, undesirable. The starting tube, when employed to suppress a current impulse on starting up, behaves in an exactly opposite manner. The use of this tube depends on the fact that the increase in temperature occupies a certain finite period of time; owing to the large mass of the resistance material the tube has a fairly high thermal capacity and hence exhibits a certain inertia. On the other hand, the inertia necessitates a certain period of cooling after the tube has been switched off, before it is ready to work properly on the next starting up. In most cases it is desirable for the resistance to again reach $^2/_3$ of its value when cold [6]). *Fig. 5* gives the cooling curves for the various types of tube illustrated in figs. 2 and 3. The cooling time is indicated in each case by a small arrow. It is seen that the cooling period is the longer the greater the starting tube.

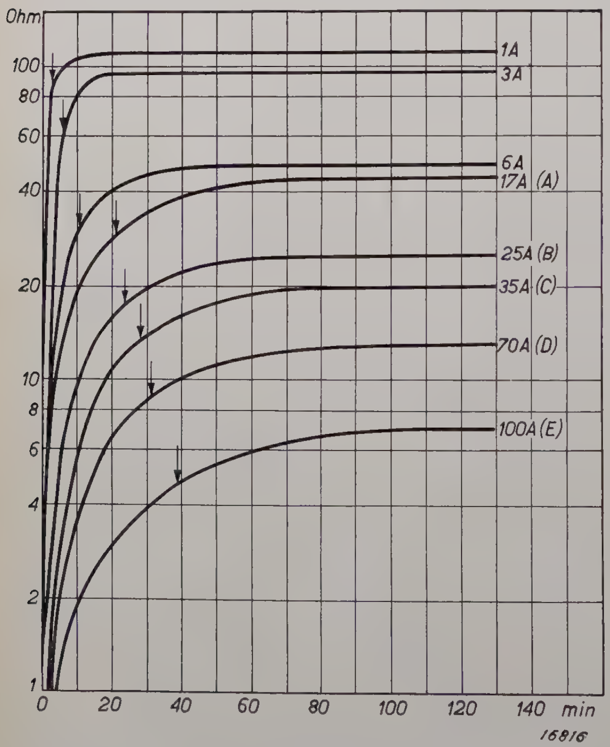

Fig. 5. Cooling curves for different types of starting tubes. The resistance in ohms is plotted as a function of the time in minutes when the tube is switched off at time 0. An arrow on each curve indicates when the corresponding tube has again reached $^2/_3$ of its resistance when cold. It is observed that the cooling time increases with the size of the starting tube.

That the "Starto" starting tubes operate at a high temperature is an advantage as regards rapid cooling. For at red heat radiation contributes appreciably more to rapid cooling, whilst in a lower temperature range cooling is due largely to convection and thus takes place much more slowly.

Applications of Starting Tubes

The use of starting resistances for reducing or preventing current impulses when switching on motors, lighting circuits, transformers, condensers, etc., offers several important advantages as compared with ordinary sliding resistances or switches. These starting resistances are fully-automatic in operation and contain no moving parts or sliding contacts which can seize. A feature of starting tubes is therefore their long life; type 3-A retains its initial characteristics when continuously loaded for more than 10 000 hours and when used 100 000 times to start a 1.3-h.p. motor. The saving in weight and space with starting tubes is also considerable; the 3-A tubes weighs only 15 gr, and the maximum overall dimensions are 2.5 × 6 cm; the corresponding data for the 100-A type are 700 gr and 9 × 25 cm.

In many cases where a consumer has hitherto been switched straight across the line because the expense of an intermediate starter was not warranted, a starting tube can now be used to advantage. Slow starting is also an advantage with impulses having a low absolute value, since for instance less maintenance is required by the motor commutators and current impulses in the mains as well the blowing of fuses are also avoided.

Starting of Motors

The resistance rod in each tube can only carry a limited amount of power without overheating, so that for each tube a maximum current rating is prescribed for continuous duty. But if the initial resistance of the current consumer is very much smaller than its final resistance, as is the case for instance with large motors, the heat generated in the starting tube will be too great if the latter has been selected on the basis of the maximum permissible current intensity marked on it; the heating up of the tube is then no longer uniform and local overheating may occur. To prevent this it is safest to select for a motor of specific current rating a starting tube rated for approximately double the maximum current [7]).

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[6]) On starting motors, in most cases a smaller increase is sufficient.

Example: A 3 h.p., 125 volts D.C. shunt-wound motor absorbs 12 amps on a 30 per cent load. A starting tube *B 125* (i.e. with 25 amps maximum current) is suitable for starting this motor on no load; the impulse on starting is found to be 19 amps [8]). When the motor has started and the starting tube is hot, the current may be increased in continuous duty to 25 amps above this level and for short periods even up to 50 per cent above. This temporary permissible overload of 50 per cent when hot applies in fact to all tubes.

It is evident that a fully-automatic series resistance cannot be used where speed control must also be provided for (as with certain D.C. motors). In other cases a consumer has to be switched on again immediately after being cut off. The difficulty of the higher starting impulse then occurring, can be met by shorting the starting tube after starting. The tube is then usually given sufficient time to cool, apart from the fact that the watt losses of the tube are eliminated. Shorting can be effected either by means of an ordinary switch or automatically by an electromagnetic relay. With the smaller starting tubes the watt consumption is frequently so small that it does not pay to short the tube to save the losses sustained.

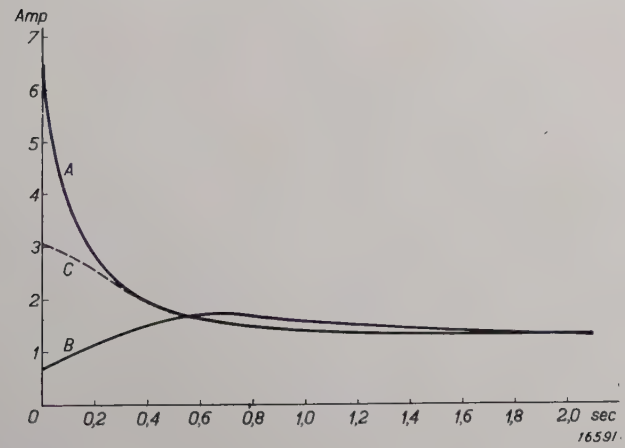

Fig. 6. Oscillogram of current on switching on a single-phase A.C. commutator motor, 220 volts, with a current consumption of 1.3 amps. *A*: straight across line, the starting impulse being 500 per cent of the working current. *B*: with "Starto" starting tube, 3-amp type, which reduced the starting impulse to 130 per cent of the normal working current. *C* with the same starting tube, switching on immediately after the motor has stopped (i.e. 7 sec. after switching off, thus representing the most unfavourable case), the impulse being 340 per cent of the normal current.

The example shown in *fig. 6* indicates the magnitude of the starting impulses, which must be reckoned with on immediately reclosing a circuit.

Slow Switching-On of Lighting Circuits

The starting impulses on closing glowlamp circuits can be suppressed with the starting tube in the same way as these tubes can be used with motors. In many cases it is desirable for the lamps to light up gradually, e.g. in cinemas, theatres, etc. The starting tube can also perform this duty, and where a comparatively long lighting-up period is necessary a tube can be selected with a maximum permissible current rating equal to double the working current of the lighting circuit (or even higher), in the same way as with large motors.

Example: Six glowlamps with a total consumption of 900 watts are connected to the 220-volts mains. The normal current is therefore 4 amps. If the lamps are to burn very weakly immediately after switching on, the initial current must be approximately half the normal, i.e. 2 amps. The resistance on switching on must therefore be 110 ohms. The six lamps in parallel have an initial resistance of approx. 12 ohms, so that the resistance when cold of the starting tube required must be approx. 100 ohms. These requirements are met by the *A 220* tube, which also has a suitable maximum permissible current rating. The current-time diagram in *fig. 7* indicates that the current increases from 50 to 90 per cent of its final value in 15 sec, a period giving every comfort to the eye.

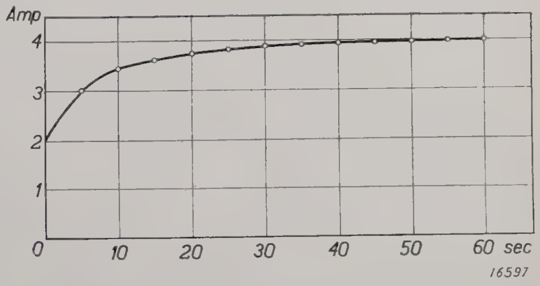

Fig. 7. Increase of current in a lighting circuit with a series-connected *A 220* starting tube. The tube has been so selected (resistance when cold), that the initial current, 2 amps, is 50 per cent of the working current. After 15 sec. the current has attained 90 per cent of its final value. This gradual lighting-up of the lamps is soothing to the eyes.

Delayed and Graduated Starting

As demonstrated particularly by the last example above, these starting tubes can also take the place of bimetallic switches for the delayed closing of electric circuits, e.g. anode circuits in rectifiers, amplifiers, relays, etc. The required time delay can be provided by suitable choice of the resistance when cold of the starting tube, and a current-time curve of the type shown in *fig. 8* can be readily obtained.

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[7]) Thus the starting tube *A* (maximum permissible current in continuous duty 17 amps) can be used for starting a small motor which on full load takes 9 amps, and for a larger motor which on no-load takes 9 amps.

[8]) The resistance when hot of the tube *B* 125 is about 0.9 ohm. If in place of the starting tube an ordinary resistance wire of 0.9 ohm is connected in series with the rotor the starting impulse will be 60 amps, i.e. three times greater.

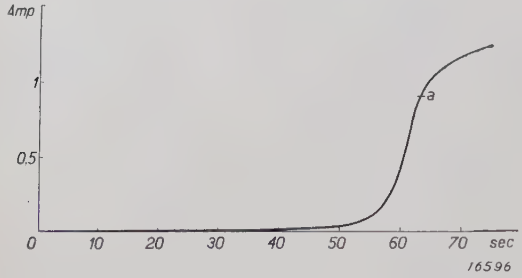

Fig. 8. Current increase with a starting tube serving as a "delay switch". This application of these tubes is chiefly suitable for switching on main feeder circuits by means of an electromagnetic relay: The auxiliary current through the relay is allowed to increase slowly by means of the starting tube connected in front of it, and only at point *a*, i.e. after a full minute, does it reach the necessary intensity to attract the electro-magnet. This offers the advantage that small types of starting tubes can still be used for heavy mains current (short cooling period).

If a specific starting current is needed, which after a definite number of minutes shall be increased, say fourfold, a starting tube of special design can be selected in which a resistance wire is connected in parallel to the starting resistance (*fig. 9*). The time delay in this case is determined by the resistance when cold of the starting rod and the heat furnished by the current flowing through the parallel resistance. In this way a great variety of currents and time delays can be obtained.

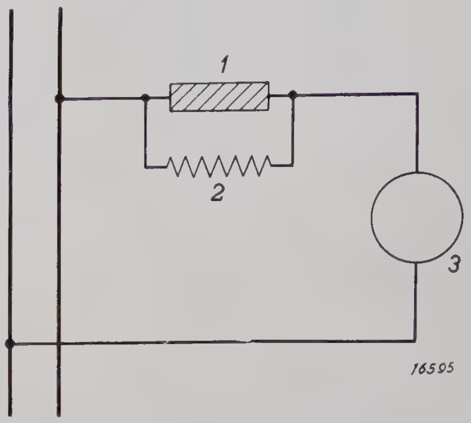

Fig. 9. Special type of starting tube for graduated starting. The glass bulb of the tube contains, in addition to the starting rod 1, also a resistance wire 2 which is connected in parallel to the rod. By this means a specific initial current is obtained at the consumer 3. The resistance when cold of rod 1 is so high that the rod cannot heat up of its own accord. The rod is gradually heated by the heat generated in coil 2; after a specific period, however, it heats up rapidly, so that the current in 3 increases to its final value.

The above considerations and examples will be sufficient to indicate that the new starting tubes possess characteristics which make them eminently suitable for many applications in electrical technology.

THE SOUND-RECORDING CUTTER IN THE PHILIPS-MILLER SYSTEM

By A. CRAMWINCKEL.

Summary. From a consideration of the requirements which the cutter used for sound recording in the Philips-Miller system has to fulfil, some dimensions are deduced for the cutter and a suitable material for it is mentioned. A brief description is also given of investigations on the durability of the cutter for sound-track recording on the "Philimil" strip.

The principles underlying the Philips-Miller method of sound recording and in particular the construction and characteristics of the sound-recording system have been discussed in detail in two previous articles in this Review[1, 2]). Sound is recorded by mechanical means by a vibrating wedge-shaped cutter S (*fig. 1*), cutting a transparent sound-modulated groove in a "Philimil" film strip. This strip is built up of a celluloid base C (similar to a photographic film), on which are laid a transparent layer of gelatin G (about 60 μ thick) and a very thin opaque coating D (about 3 μ thick). A transparent track on an opaque background is produced by the removal of the opaque coating along the groove made by the cutter.

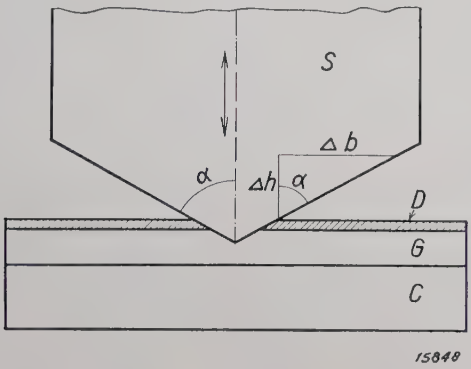

Fig. 1. The wedge-shaped cutter and the "Philimil" strip used for sound recording in the Philips-Miller system. The "Magnification" obtained in the recording of the sound track is $2\Delta b/\Delta h = 2\tan\alpha$;

The cutter being shaped like a blunt wedge, small cutter amplitudes Δh are converted to magnified variations in the width $2\Delta b$ of the engraved track. It is just this magnification which has enabled the advantages of mechanical registration of the vibrations of a linear-amplitude system [1]) to be utilised.

In this article an outline will be given of the investigations which have been carried out regarding the shape of the cutting unit and of the results which have been obtained in this direction. The cutter has to meet the following requirements:

1) It must magnify the vibrations of the reed of the sound recorder 40 times [3]) and register them on the film without distortion, even up to the highest audio-frequencies with the maximum amplitudes which may occur in the vibrations to be registered.
2) It must be so stable that during recording no wear takes place that is likely to have an adverse effect on the quality of the sound reproduced.

The first requirement determines the dimensions of the cutter. Fig. 1 shows that the amplitude $2\Delta b$ of the modulated sound track is:

$$2\Delta b = \Delta h \cdot 2\tan\alpha$$

The required magnification $2\Delta b / \Delta h = 40$ gives the apical angle of the cutter $\alpha = 174$ deg; the sides of the wedge therefore make an angle of only 3 deg. with the surface of the strip. The small value of this angle naturally considerably enhances the requirements which determine undistorted reproduction, as regards the smoothness of the cutting edges, the flatness of the strip and the accuracy of the attachment of the cutter.[4])

The angle β of the cutter (see *fig. 2*) may vary within certain limits. It must not, however, be too large, as the maximum gradient φ which the cutter can inscribe on penetration is limited by the rear slope R of the cutter, being determined by the relation $\varphi + \beta = 90$ deg. The maximum amplitude which can be registered is proportional to the length of the inscribed wave, and hence for a given velocity of the strip it is inversely proportional to the frequency. *Fig. 3* shows this relation for various cutter angles. Each sloping line gives the maximum width of sound track for a specific cutter angle. Thus, with the cutter angle of 55 deg. employed in actual practice a sound with a 4000-cycle frequency can be inscribed with a maximum track width of only 1 mm (instead of 2 mm wide as would be obtained with the full amplitude of the cutter of 25 μ. The curve also included in this figure represents the maximum amplitudes of the various frequencies occurring in music and speech.

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[1]) R. Vermeulen, Philips techn. Rev. **1**, 107, 1936.

[2]) A. Th. v. Urk, Philips techn. Rev. **1**, 135, 1936.

[3]) As already stated in this Review [2]), the vibrations of the reed in a sound recorder of the type constructed here, amount to only a few hundredths of a mm. To obtain a modulated sound track with a width of 1.8 mm, high magnification is therefore indispensable.

[4]) To avoid distortion of the track, the plane of intersection of the cutter with the film must be exactly perpendicular to the direction of motion of the strip. A slight lateral displacement of the cutter axis, such that the two cutting edges make different angles with the plane of the film, is, however, not deleterious. The sound track becomes unsymmetrical as a result thereof, but no distortion occurs on reproduction.

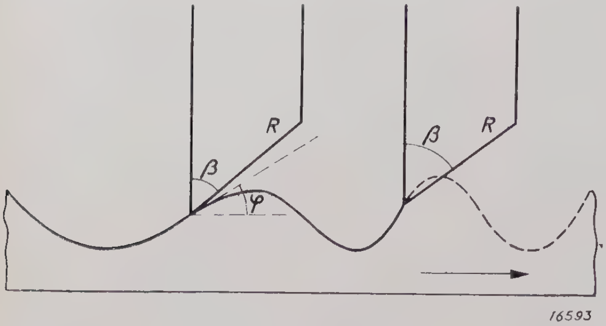

Fig. 2. Limitation of the cutter amplitude;
Left $\varphi + \beta < 90$ deg, possible.
Right $\varphi + \beta > 90$ deg, impossible.
The maximum slope φ which the cutter can inscribe on penetrating the strip, is determined by the condition that $\varphi + \beta = 90$ deg.

This curve was derived by Fletcher from measurements by Sivian, Dunn and White [5]). The maximum occurring at 300 cycles would here give the maximum amplitude of 2 mm. It is seen that at $\beta = 55$ deg. the amplitude only becomes limited by the rear of the cutter above 8000 cycles. But even at 15000 cycles the limitation in registration is only 3 decibels [6]), so that it does not appear useful to make the cutter angle smaller still (especially as the stability and durability of the cutter increase with its apical angle).

The second requirement for maximum durability and stability of the cutter called for the selection of a suitable material, since, as we have seen, the cutter angles are already fixed. In this direction it was first necessary to elucidate the exact causes responsible for the wear of the cutter.

It was found that by increasing the purity of the gelatin the life of the cutter could be considerably lengthened. It thus appeared that the cutting work done on the gelatin was not itself responsible for the wear, but that the impurities, such as dust particles, etc., which were sporadically embedded in the gelatin were the primary cause.

Owing to the great hardness of these particles the cutter must be made of a very hard material, whilst the extreme local concentration of stresses due to these particles also called for maximum homogeneity. The toughness of the cutter material

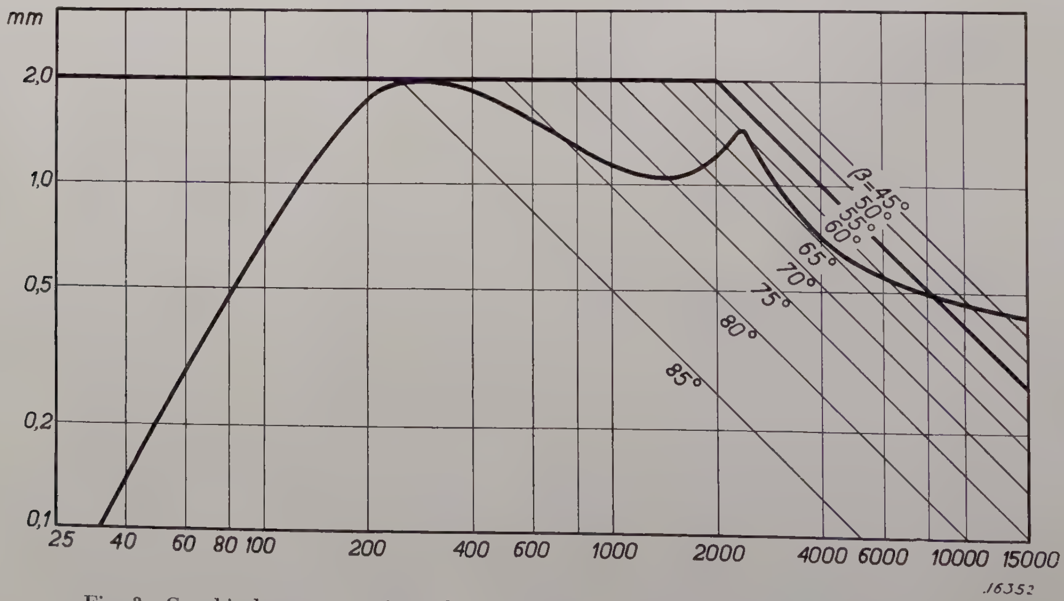

Fig. 3. Graphical representation of the limitation of the cutter amplitude a, plotted against the frequency ν. For each of a number of cutter angles β a sloping line is drawn, which indicates directly the maximum width of the sound track in mm that can be obtained at each frequency. The drawn curve indicates the actual amplitudes (widths of sound track) of all frequencies occurring in normal music and speech. Where a sloping line cuts the curve, the actual limitation of the amplitude begins at the corresponding cutter angle.

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[5]) L. I. Sivian, H. K. Dunn, and S. D. White, J. acoust. Soc. Amer., **2**, 330, 1931.
H. Fletcher, Bell, Syst. techn. J. **10**, 349, 1931.

[6]) Corresponding to a factor 1.4 in the amplitude, which at these high sounds cannot be detected by the ear.

appears to be only of secondary importance. Various types of steel with Vickers-hardness values[7]) between 800 and 900 were not found hard enough at the outset; this may in fact be gathered from the micrograph of the sound track obtained with a worn steel cutter shown in *fig. 4*. On the other hand various sintered substances, such as the carbides of the heavy metals, which had a much greater hardness (Vickers values between 1300 to 1800) were found to be too inhomogeneous (cf. the etched section in *fig. 5*). The material finally selected, viz, sapphire in single-crystal form, incorporated the two requisite properties: Being of single-crystalline structure, it is naturally completely homogeneous (cf. the Laue diagram in *fig. 6* obtained with X-rays; an etched section similar to that in fig. 5 would have been useless here, as it would not have revealed any structural details); moreover, its Vickers hardness value is approx. 1850. On Mohs's scale of hardness sapphire has a hardness 9 as compared with diamond, the hardest substance known, which has a hardness of 10 on this scale. Between these two there is for instance silicon carbide with a Vickers hardness value of about 2100[8]). This material was also tried as a cutter and, although it was found quite suitable, it is difficult to obtain it in the form of large crystals. The same also applies to zirconium oxide, boron carbide (Vickers hardness about 2600; this material has very nearly the same hardness as diamond[8]), and other carbides, such as the metallic carbides already referred to, which would probably also be quite

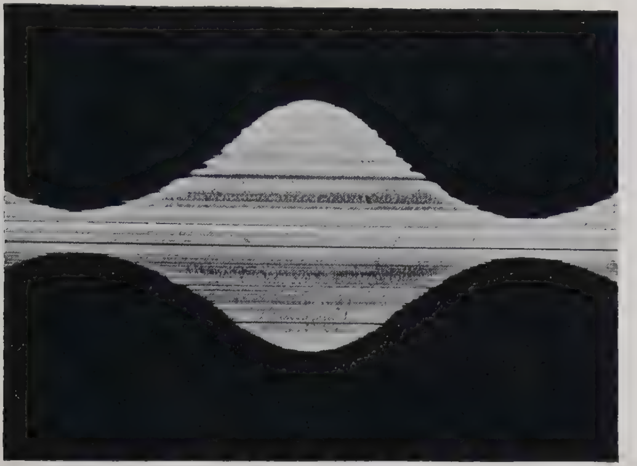

Fig. 4. Micro-photograph of a sound track obtained with an experimental cutter made of an alloy steel, after having recorded a path equivalent to a sound track on 400 or 500 m of "Philimil" strip. The cutting edge has become very jagged and has acquired a large number of notches (indicated by the thin continuous lines and the rough edge of the sound track due to the retention of the coating at certain points). The frequency of the sound registered was 150 cycles. Magnification × 18.

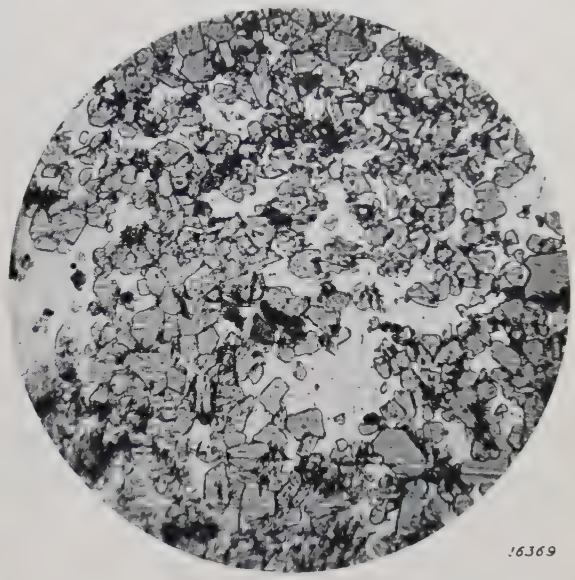

Fig. 5. Etched section through a sintered material, magnification × 100. The individual particles can be clearly picked out; these are composed of a very hard metallic carbide and held together by a soft tough binding medium. The material is evidently very inhomogeneous.

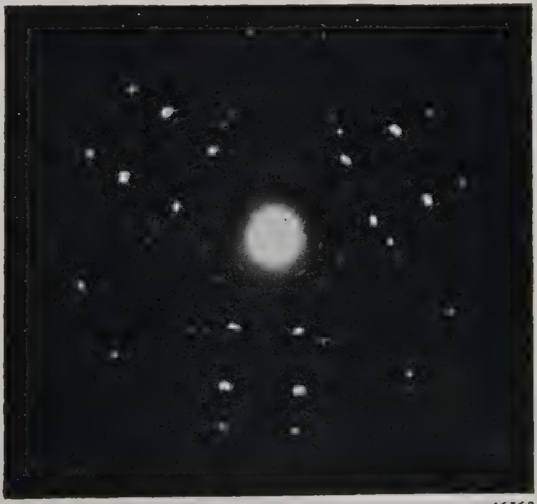

Fig. 6. X-ray diagram of a sapphire single crystal (Laue diagram). The complete homogeneity of the single crystal is indicated by the sharpness and, on suitable orientation to the crystal axes, by the symmetrical distribution of the X-ray diffraction spots (cf. also this Review, 1 60, 1936).

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[7]) In measuring the hardness with the Vickers apparatus, a diamond point in the shape of a square pyramid with an apical angle of 118 deg. is forced into the material with a given force. Compared with other methods for measuring hardness, the Vickers method offers the advantage that it can be used equally well for the softest and hardest materials and gives fairly accurate results. For research purposes the Vickers hardness scale is therefore always used in this Laboratory.

[8]) A Vickers hardness value cannot be very well given for diamond, which in fact follows from the definition given in footnote [7]). It would in any case be greater than 2600.

suitable materials if they could be obtained in sufficiently large single crystals. Natural and synthetic sapphire reveal no appreciable difference in quality. Also the orientation of the cutting edges of the cutter with respect to the crystal axes does not call for special consideration with sapphire, in contradistinction to the other crystals tested, such as spinel, corundum and silicon carbide. Micro-photographs of a sound track obtained with a sapphire cutter, on first use and after recording a length of track corresponding to 500 m of "Philimil" strip, are shown in *fig. 7*. It is seen that comparatively few notches have been produced in the cutter edge, these not being detectable acoustically; there is, moreover, no question of any pronounced jaggedness of the edges (such as may be seen on the steel cutter in fig. 4) [9]). As the standard length of a roll of "Philimil" strip is 300 m, the durability of the cutter is equal to recording the maximum sound track which can be obtained on a single film, and the general rule applies that the cutter requires changing after each roll of film.

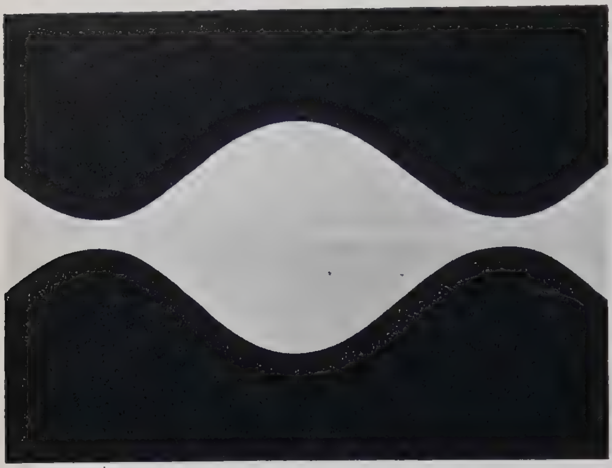

Fig. 7a. A perfect sound track recorded by a sapphire cutter on first use.

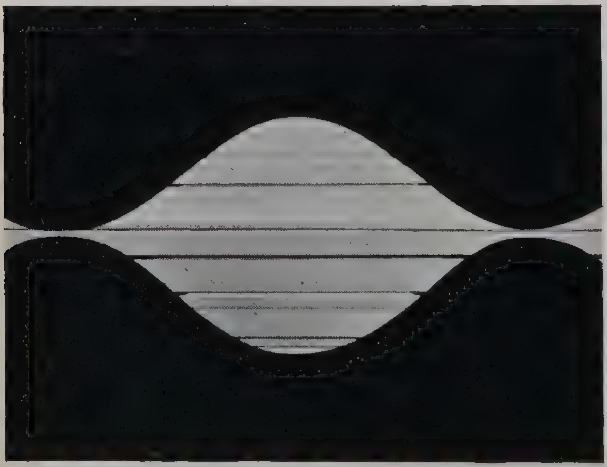

Fig. 7b. Sound track obtained with the same sapphire cutter after performing the same amount of recording as the cutter shown in fig. 4. The present cutter shows much less wear than the steel cutter in fig. 2; the edge has not become jagged and only a few notches are visible (indicated by the continuous lines and jagged edges of the sound track). Frequency and magnification are the same as in fig. 4.

The ease with which the cutter can be fixed in the sound recorder and changed for a new one may be gathered from *fig. 8*.

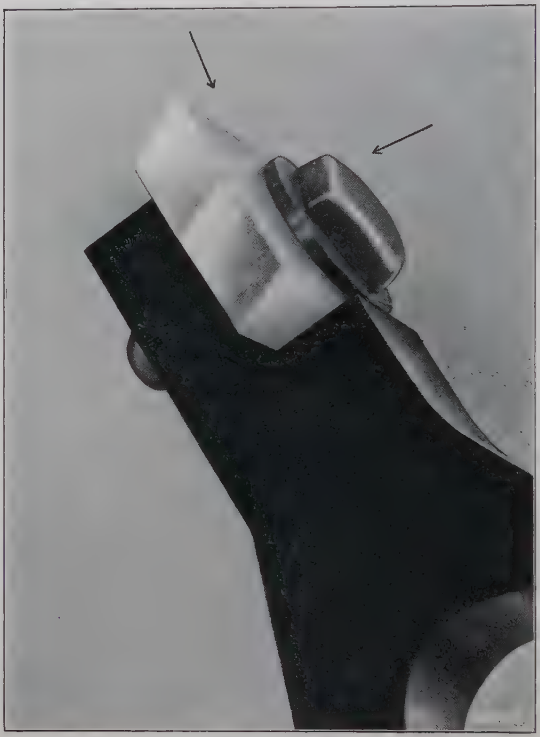

Fig. 8. Attachment of cutter to the armature extension of the sound recorder. When inserting, the cutter is pressed against the machined contact surfaces in the direction of the two arrows and is screwed tight by means of a small spanner (strongly magnificated).

In designing the clamping arrangement, the principle followed was that the cutter and the end of the recorder reed must be as light as possible in order that the recorder shall not be unnecessarily burdened with a high inertia when registering high frequencies.

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[9]) Although the micro-photograph applies to the low frequency of 150 cycles it is nevertheless applicable to average working conditions, for during recording the sound generator traversed all frequency values. A point corresponding to a lower frequency was photographed solely for the sake of clarity. It was found, moreover, that the wear of the cutter depended to no appreciable extent on either the frequency or the amplitude.

VISUAL ACUITY AND SPEED OF VISION IN ROAD LIGHTING

By P. J. BOUMA.

Summary. The relationship is investigated between the visual acuity on the one hand and the brightness levels of the object and the background, the type of illumination (monochromatic and other types of light), the distance of the observer from the object and monocular or binocular vision on the other hand. With technical sources of light the visual acuity is considerably greater with sodium and mercury light than with ordinary glow lamp and neon light. The speed of vision is investigated for various types of light: a) For stationary objects mercury and sodium lamps are better than glow lamps and neon light, b) for moving objects the descending sequence is sodium light, glowlamps, mercury light.

In observing objects on artificially-illuminated high-ways the first requirement is to perceive the presence of the object. This perception is rendered possible by the existence of a contrast between the object and the road surface; contrast sensibility and contrast richness are determining factors here.

When an object has been once perceived it is then necessary to recognise it, i.e. to observe its exact form and to estimate its distance. This recognition is governed directly by another property of the eye, viz, its visual acuity, which is defined as the ability to differentiate between the form of certain objects which are viewed with a small angle of vision, or the ability to distinguish as separate entities objects situated close together (e.g. two dots or a number of parallel lines).

In addition to visual acuity, the speed of vision is also an important factor in visual recognition; rapid recognition of an object on a highway is of the greatest importance.

As a numerical measure of visual acuity we could, for instance, take the angle of vision at which two parallel lines are still just perceptible as separate entities. But since it is preferable to allot to the greatest visual acuity the highest numerical value, the visual acuity is usually expressed as the reciprocal of this angle (in minutes). Another method of measurement would be to give the distance at which a circle and a square with a diameter of 1 cm could still just be differentiated. These measures are inter-related as follows:

$$1 \text{ minute}^{-1} \text{ corresponds to } 690 \text{ cm.}$$

The visual acuity is determined, *inter alia*, by the following factors:

A) Physical Factors
  1) The brightness of the object perceived.
  2) The brightness of the background.
  3) The physical composition of the light.
  4) The distance at which the object is perceived.

B) Characteristics of the Eye
  5) Myopia (shortsightedness) or hypermetropia (longsightedness).
  6) Astigmatism.
  7) Chromatic and spherical aberration.
  8) Size of the photo-sensitive elements of the retina.

C) Methods of Measurement
  9) Choice of object.
  10) Monocular or binocular vision.
  11) Disturbing secondary influences. Glare.

Certain of these factors require only very brief reference. We shall consider only a "normal" or emmetropic eye; for monochromatic light from the centre of the visible spectrum this eye will exhibit neither myopia, hypermetropia nor astigmatism. We shall not discuss the question of glare either but shall assume that any similar disturbing influences are entirely absent. All other factors will be dealt with in some detail.

The relation between visual acuity and the two contrasting brightnesses can be represented in different ways. To read off directly the visual acuity for two given brightness levels, the best method is to employ a diagram with the brightness levels H_1 (background) and H_2 (object) plotted as abscissa and ordinate and to insert the lines of constant visual acuity G. This has been done in *fig. 1* for sodium light; the objects viewed here consisted of a series of circles and squares, and the distance at which the square with a length of side of 1 cm would still just be distinguished was taken as a measure of G. The results apply to ordinary conditions of road lighting, where the brightness of the object is smaller than that of the background ($H_2 < H_1$). The following points may be deduced, *inter alia*, from the diagram:

1) An increase in H_2 results in a diminution of the contrast and hence a decrease of G.
2) An increase in H_1 results in an increase in the contrast and hence an increase in G.

The increase does not, however, exceed a certain limit, which in the present case is about 860 cm (1.25 minute^{-1}). This limit is reached when the image on the retina of the feature to be differentiated becomes the same size as the photo-sensitive elements. Under ordinary road lighting conditions, e.g. $H_1 = 0.3$, $H_2 = 0.06$ candles per sq. m, where $G = 530$, we are usually far below this limit.

3) Increasing H_1 and H_2 in the same ratio, in fig. 1, proceeding in a direction parallel to the line $G = 0$ (for instance by increasing the intensity of illumination), results in an increase in G; thus, if we double H_1 and H_2 in the example cited above, G will already increase to 600; here again the limit $G = 860$.

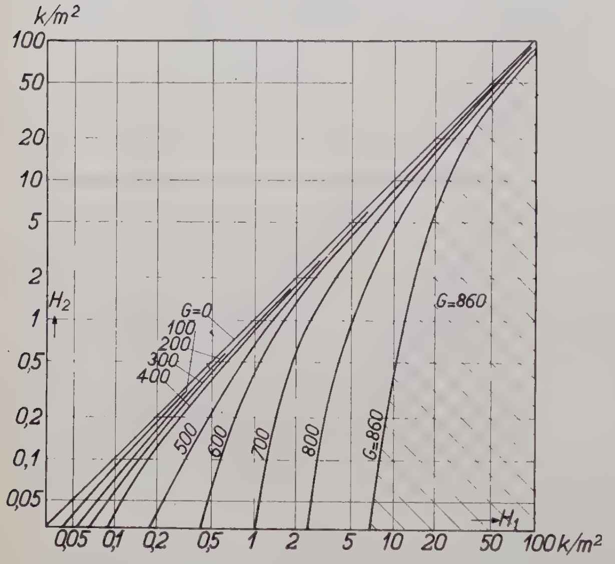

Fig. 1. Visual acuity G as a function of the brightness (in candles per sq. m) of the background (H_1) and of the object (H_2) with sodium light (Bouma).

To compare the visual acuity with different types of light, a diagram such as that shown in *fig. 2* will be found more useful and suitable. In this diagram the visual acuity G is plotted as a function of the brightness H for the following types of light: *1* mercury light; *2* sodium light; *3* neon light; *4* neon light (only the red lines); *5* white light (glow lamps), and *6* the blue mercury line, taking in every case a fixed ratio of H_1 to H_2 (here 1 : 12, i.e. for a bright object on a dark background). The curves for the green and the yellow mercury lines almost coincide with those for the total mercury light. It is seen from the diagram that the visual acuity with mercury light and with sodium light is considerably greater than that with white light. A correct idea of the magnitude of the difference between sodium light and white light is afforded by the ratio of the brightness levels required with white light and with sodium light in order to obtain an equivalent visual acuity G in both cases. This factor f is on the average 2.5 for the range under measurement, in other words the same visual acuity G is obtained when the brightness with white light is 2.5 times greater than that with sodium light. The main reason for this difference is the chromatic aberration of the eye, which adversely affects the definition of the image on the retina in the case of white light, an effect which is absent with the almost-monochromatic sodium light. Closer investigation shows that all monochromatic colours (with the exception of the shortest wave lengths, viz, blue and violet) give a greater visual acuity than white light. This difference also can be expressed by a corresponding factor f. In *fig. 3*, f is plotted as a function of the wave length λ for monochromatic light: Curve *1* is based on the average of measurements made

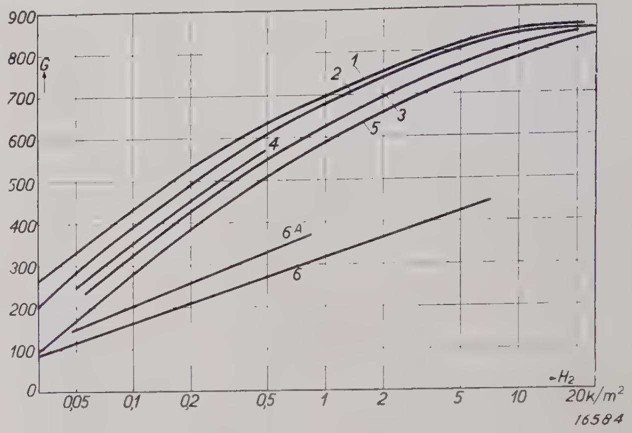

Fig. 2. Visual acuity G as a function of the brightness H_2 (in candles per sq. m) of the object (brightness of background $H_1 = 1/12\ H_2$) for: *1* mercury light; *2* sodium light; *3* neon light; *4* red neon light; *5* glowlamp light; *6* blue mercury line; *6a* as *6* after correction for myopia (Bouma).

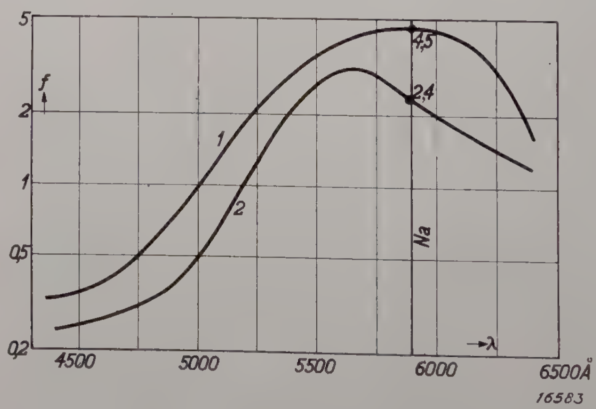

Fig. 3. Ratio f of the brightness levels of white and monochromatic light required to obtain the same visual acuity (various investigators): *1* for line grating as object; *2* for other objects.

by Ives and Luckiesh, and curve *2* on the average of measurements made by Arndt, Bouma, Korff-Petersen and Ogata (in all cases at approx. 1 candle per sq. m). That these curves do not coincide, is due to the fact that different objects were employed in the two series of experiments; the first-named investigators used a grating of parallel lines, and the latter more symmetrical objects, such as letters, Landolt rings, circles and squares. The difference is particularly pronounced in the case of sodium light (5890 Å): $f = 4.5$ for the line grating and 2.4 for the other objects. For practical purposes curve *2* is the more important, and according to this curve the greatest visual acuity is obtained at 5600 Å (not far from the point where the visibility factor of the eye is also a maximum), whilst the acuity for red rays is practically the same as for white light, but that for blue light is much lower. The fact that mercury light gives such a high visual acuity, is also accounted for by fig. 3: the intense green and yellow mercury lines (5461, 5770 and 5790 Å) are both in very favourable positions, and since they are still close together they do not create any marked interference; the blue line (4358 Å) also causes little trouble owing to its very low intensity.

The low visual acuity with blue light is partly due to the fact that the eye is myopic for this short wave length. That the main cause is, however, of different origin is indicated by curve 6^A in fig. 2 where a correction for myopia has been made. The improvement is seen to be only slight.

Of the various factors referred to at the outset we have not dealt with two of these in detail, viz, monocular and binocular vision and the effect of the distance of the object.

Regarding the first factor, it has been found (Blondel, Ferree, etc.) that binocular vision gives a better visual acuity than monocular vision, provided both eyes are identical (either naturally or after suitable correction); where the eyes are not equivalent, visual acuity in binocular vision is determined by the eye with the best accomodation; closing the other eye then has no effect.

In conclusion the effect of distance should be discussed. It seems reasonable to assume that for the normal eye the visual acuity (which is ultimately determined by the *angle* of vision) is independent of the distance; in other word, if a square of 1 cm can still just be distinguished at a distance of 6 m, it might be expected that a square of 2 cm would still just be distinguishable at a distance of 12 m. This has, however, been found not to be quite the case. Measurements by Freeman, Luckiesh, Bouma and Mouton indicate that for distances less than 2 m the visual acuity *G* increases with the distance *d*, that for *d* between 2 and 7 m. *G* is practically independent of the distance, and for greater distances gradually diminishes with the distance. *Fig. 4* shows this relation graphically; the cause of this phenomenon is still unknown. The diagram applies to the normal eye; a myopic eye would for instance exhibit a much greater decrease of *G* at greater distances.

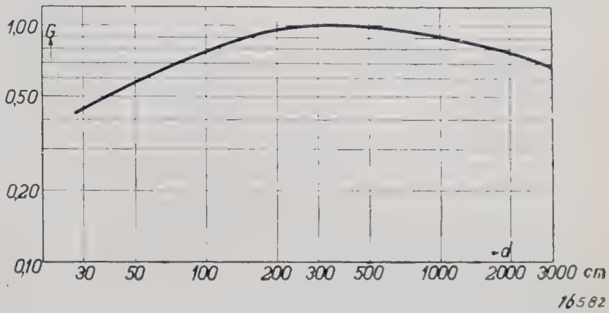

Fig. 4. Visual acuity G as a function of the distance *d* (various investigators).

In the above discussion an important factor has been left entirely out of consideration, viz, the time, a factor which in reality plays an important part on the road. In all the measurements referred to, the eye has been given an opportunity to observe the stationary object for an unlimited period. These experiments may be extended in two directions:

1) The eye is allowed to observe the object for only a short time.
2) The object is caused to move in the field of vision.

Restricting ourselves first to the first-named case, it is interesting to know the time τ during which an object must remain in the field of vision in order to make recognition possible. This time interval depends on the nature and size of the object, on the distance separating it from the observer, and on the brightness levels of the object and the background. If we alter only the intensity of illumination (such that the two brightness levels are altered in the same ratio) it will be found that below a certain brightness H_0 of the object the latter will no longer be distinguishable at all; this limit H_0 may be deduced from the measurements of visual acuity. At brightness levels which are only slightly above H_0, τ becomes very large and the magnitude $1/\tau$, which is frequently termed the speed of vision, approaches zero. *Fig. 5* gives an example of the variation of this factor $1/\tau$ being plotted as a function of the brightness *H* of the object (a number of circles and squares of 1 cm diameter were viewed from a distance of 2 m). The ratio of the brightness levels of the object and the background was here 12 : 1; the short exposure times were obtained by means of a Compur shutter. Curve *1* applies to sodium light and curve *2* to glowlamp light. The following points may be noted:

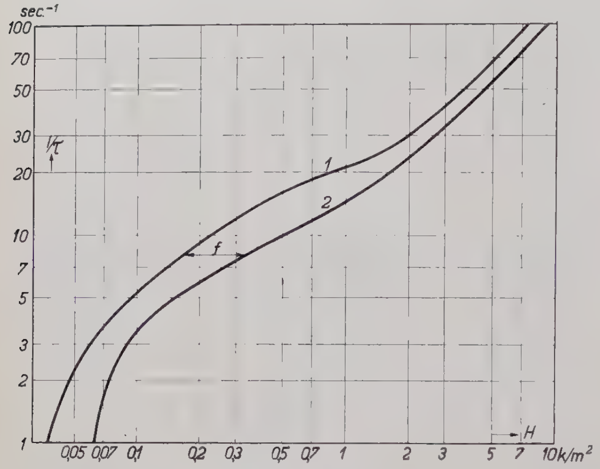

Fig. 5. Speed of vision $1/\tau$ (τ is the time for which the stationary object must be illuminated in order to be perceived) as a function of the brightness H (in candles per sq. m) of the object (Bouma): *1* sodium light; *2* glowlamp light.

1) The curves do indeed approach zero for the values $H_0 = 0.032$ and $H_0 = 0.060$ which we can also obtain from fig. 2 for $G = 200$.
2) The speed of vision is always greater for sodium light than for white light, or expressed otherwise: To obtain the same $1/\tau$ values a higher brightness level is required with white light than with sodium light. If we represent the ratio of the required brightness levels again by f (exactly as in the measurements of visual acuity), we see that at low brightness levels f is roughly equal to 2, whilst at high brightness levels (above the brightness level of road lighting) f is about 1.2.
3) At high brightness levels $1/\tau$ becomes proportional to H, i.e. whether an object is perceived depends solely on the magnitude τH and hence on the total quantity of light falling on the eye. Over these short time intervals the eye integrates the brightness within the period of exposure (exactly as does a photographic plate).

It was found for various monochromatic and technical sources of light that the values of f occurring at the speed of vision are in agreement with those from measurements of the visual acuity (Arndt). In particular the speed of vision is thus also greater with sodium and mercury light than with glowlamp light; this applies especially to objects which are viewed under a small angle of vision (Luckiesh).

The conditions are somewhat different if at the same time the object is moved (thus simultaneously extending the visual acuity experiments in the two directions indicated). Investigations on these lines were carried out, *inter alia*, by Weigel, who determined the time τ' during which a moving object must be visible in order to be recognised. The velocity of the object was in all cases such that during the time in which the object was visible the same distance was always traversed. *Fig. 6* shows some of the results obtained, where for various types of light (*1* sodium light, *2* glowlamp light, *3* mercury light) $1/\tau'$ is plotted as a function of the brightness of the background (the brightness of the object was always 2.2 times greater). As in the measurements made by Arndt and Bouma, sodium light is again also seen to give much better results than glowlamp light. Compared with the previous measurements there are, however, two important differences:

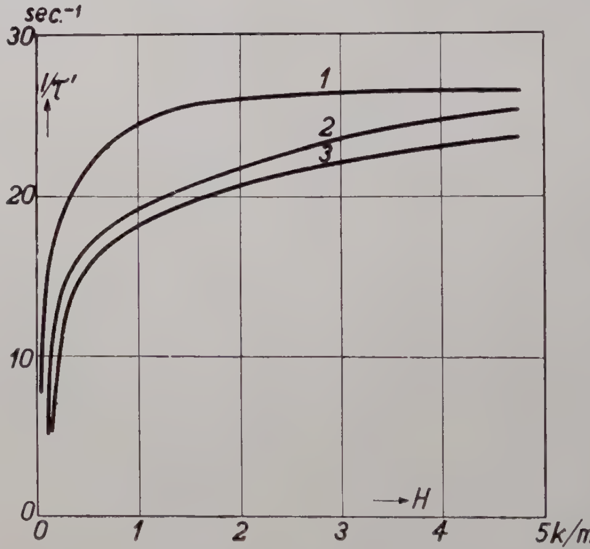

Fig. 6. Speed of vision $1/\tau'$ (τ' is the time during which a moving object must be illuminated in order to be perceived) as a function of the brightness H (in candles per sq. m) of the background (Weigel).
1 sodium light; *2* glowlamp light; *3* mercury light.

1) The magnitude τ' rapidly reaches a saturation value of about $^1/_{25}$ of a second, whilst τ measured for stationary objects may be reduced with high brightness levels to $^1/_{200}$ (Bouma, Cobb) and even to $^1/_{500}$ of a second (Ferree, Rand).
2) For moving objects, the speed of vision with mercury light is in fact smaller than with glowlamp light (Weigel), whilst it is much greater with stationary objects (Arndt).

These differences can to some extent be accounted for. At very short exposure times Weigel employed very high velocities for the object, so that the eye was no longer able to follow the movements of the object. Even at the highest brightness levels such short times of perception are therefore no longer able to give satisfactory vision, hence the saturation value. That the chromatic relationship of τ' may differ from that of τ is evident when it is remembered that here entirely different properties of the eye are called into operation, particularly the speed at which the image disappears from the retina. If we assume that this speed is smaller with blue light than with other kinds of light, it is clear that sodium light under these conditions is considerably superior to both mercury light and glowlamp light.

It may be advanced against the above discussion that on the highway we are not only interested in the time during which an object must be visible to us, but also particularly in the time elapsing between the first appearance of the object and the instant at which an impression has been conveyed to the brain, and the object is actually recognised for what it is. This interval obviously also embraces a psychological reaction time, viz, the time elapsing between the formation of the complete image on the retina of the eye and the instant at which it has been registered on the brain and the latter reacts to it. Although it appears plausible that this reaction time will be the same for different types of light, it is nevertheless important to investigate whether, in this respect also, sodium light offers any advantages over ordinary glowlamp light.

Information of the total time taken by the whole operation of a registration on the brain is given by the results of experiments on the speed of reading. *Fig. 7* shows the speed of reading in letters per second for various brightness levels of the page and for both white light and sodium light. It is seen that also in this repect sodium light is superior to white light, and for f we again get, as was to be expected, approximately the same value as was determined for visual acuity and speed of vision ($f \sim 2$).

Unlike fig. 5, fig. 7 naturally reveals a saturation value determined by the speed at which our mind is able to "digest" the matter, this saturation value is the same for both types of light.

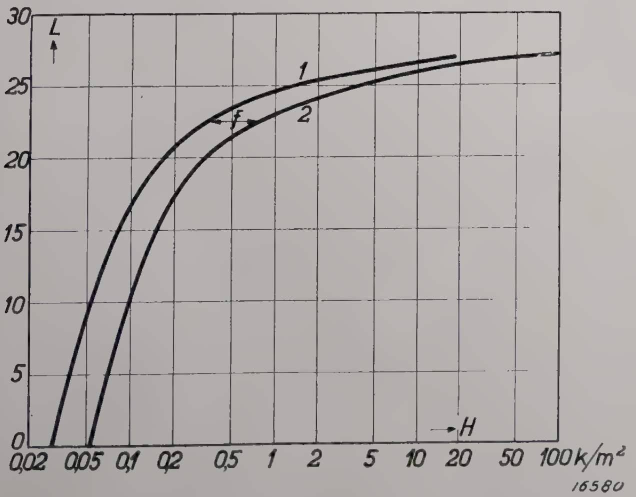

Fig. 7. Speed of reading L (in letters per second) as a function of the brightness H (in candles per sq. m) of the page (Bouma): *1* sodium light; *2* glowlamp light.

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PRACTICAL APPLICATIONS OF X-RAYS FOR THE EXAMINATION OF MATERIALS

By W. G. BURGERS.

Up to the present we have discussed in this section only X-ray photographs of pure compounds having a specific chemical composition and in which the various elements are present in fixed quantitative proportions. Where mixtures of such compounds were considered, as in the two previous articles, the compounds were present as independent physical entities. But substances are known which are composed of several elements or compounds in varying proportions, although one phase is present. In these cases we speak of solid solutions or mixed crystals, and in the case of metals frequently of alloys.

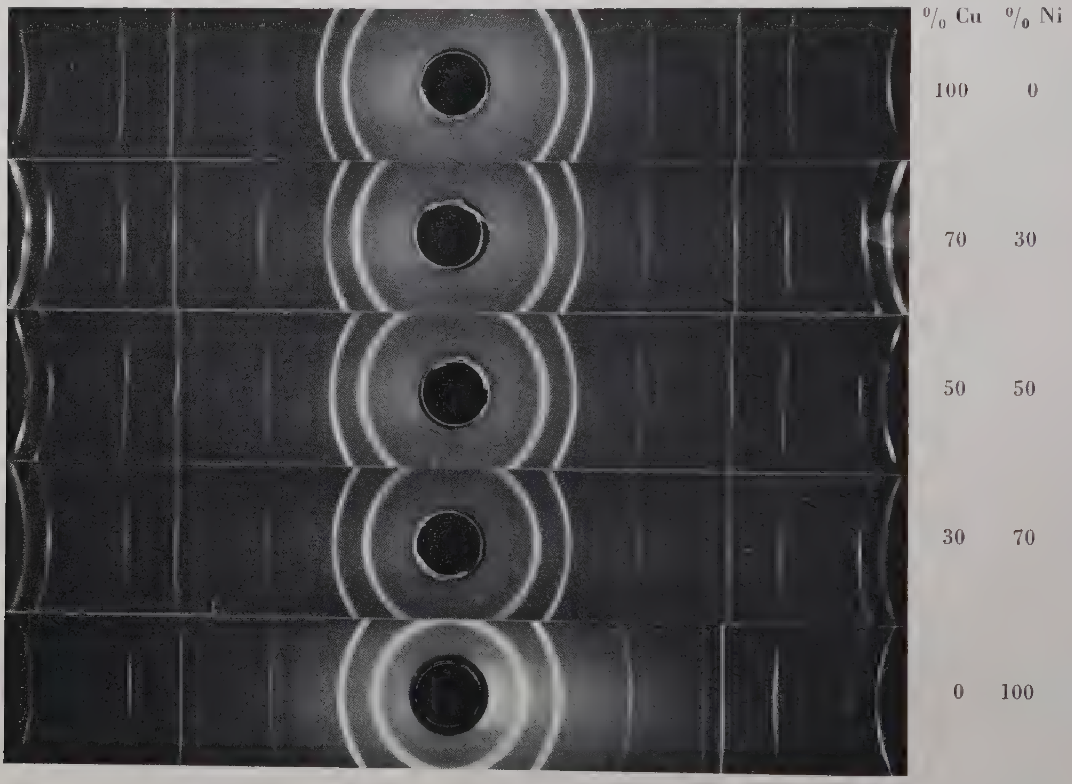

Fig. 1. X-ray photographs of copper-nickel alloys of different compositions.

Mixed crystals are frequently formed by elements or compounds having identical crystal lattices in which only the interatomic distances may have different values. Examples of these "isomorphous" crystal structures are found in many metals as well as in compounds of corresponding composition, e.g. barium and strontium carbonate, $BaCO_3$ and $SrCO_3$. Hence these elements or compounds are often "miscible" with each other in all proportions. The conception is that, for instance, in the case of $BaCO_3$ and $SrCO_3$ the barium and strontium atoms, which occupy very definite positions in the crystal lattices of the homogeneous compounds, are arbitrarily distributed over these positions in the mixed crystal.

Owing to the difference between the interatomic distances in isomorphous crystals referred to above, it must be expected — and this is actually found to be the case — that the interatomic distances in a mixed crystal (in which only a "mean" interatomic distance can be assumed owing to the different atoms alternating with each other) have values between those for the two components. Closer investigation has shown that the interatomic distances in a series of mixed crystals vary in general in proportion to the composition.

The occurrence of isomorphism and the formation of mixed crystals are readily brought into evidence by X-ray photographs, for since in isomorphous crystals the same arrangement of atoms is found, with only a difference in their distances, they give

X-ray photographs in which the interference rings occupy the same relative positions but have different diameters. These diameters are in fact determined by the angles of dispersion of the incident X-ray beam produced at the atomic lattice, the angles varying with the interatomic distances.

Thus, if we compare the X-ray photographs obtained with a series of isomorphous crystalline bodies, the corresponding rings are found to be displaced with respect to each other.

Fig. 1 a-e shows a series of photographs for mixed crystals, which were obtained with copper-nickel alloys containing 0, 30, 50, 70 and 100 per cent nickel respectively. The progressive increase in the diameter of the corresponding interference rings is brought out very clearly here.

The presence of an alloy or a solid solution can therefore be assumed when the X-ray photograph of the substance under examination is comparable to those obtained with the isomorphous substances concerned, but differs from the latter in the size of the interference rings. From the magnitude of this difference, bearing in mind the above-mentioned consideration, it is possible to deduce the approximate composition of the solid solution.

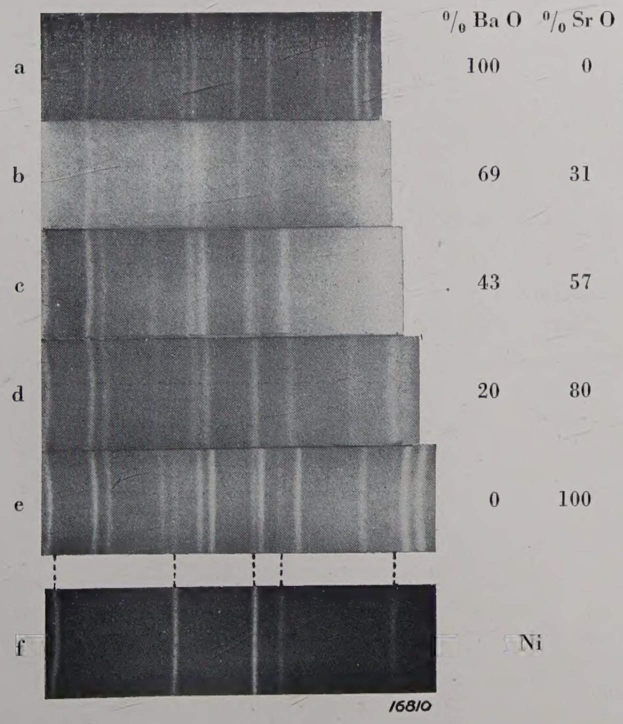

Fig. 2. Formation of mixed crystals between Ba0 and Sr0. Fig. e contains some lines which, on comparison with the nickel diagram *f*, are seen to be due to the nickel tube which carries the oxide layer.

A number of examples are given below in which the occurrence of mixed crystals or solid solutions was of interest.

12. Mixed crystal formation in oxide cathodes

The "oxide layer" of oxide cathodes consists principally of barium oxide and strontium oxide, these oxides being formed by decomposition of the corresponding carbonates. The latter are sprayed on the cathode (e.g. a short nickel tube) in the form of a paste and during preparation are decomposed by strongly heating *in vacuo*. At the high temperature of formation applied the oxides form mixed crystals as a result of diffusion 1). This can be proved by X-ray methods as demonstrated by *fig. 2 a-e*. This figure reproduces a series of X-ray photographs of oxide preparations obtained by strongly heating carbonate mixtures containing different proportions of $BaCO_3$ and $SrCO_3$. It was found that the formation of mixed crystals influenced the emissivity of the cathode 2).

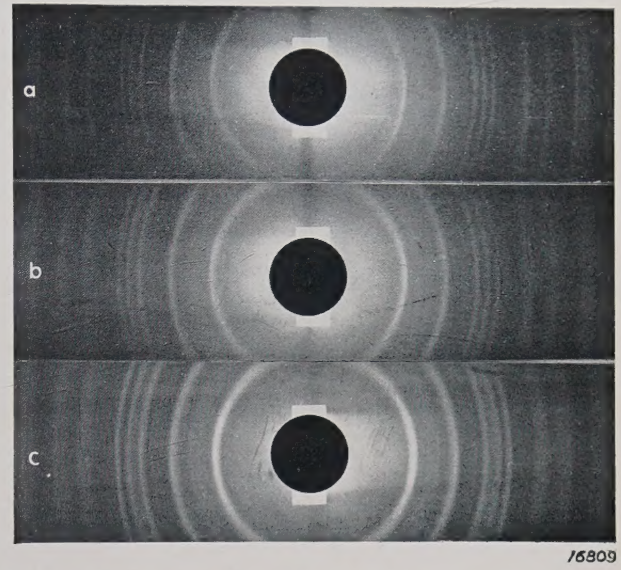

Fig. 3. Formation of mixed crystals between $BaCO_3$ and $SrCO_3$ on simultaneous precipitation from a solution of the nitrates.
a) $BaCO_3$; b) $BaSr(CO_3)_2$; c) $SrCO_3$.

Radiographic examination of a number of cathodes from standard valves showed, however, that mixed-crystal formation was not always complete. In some cases the photographs indicated that the separate oxides were still present 3), probably owing to the fact that in the preparation of the cathodes the duration of heating and the temperature were not the same in all cases, the time being too short in some for complete formation of mixed crystals.

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1) W. G. Burgers, Z. Phys. **80**, 352, 1933.

2) M. Benjamin and H. P. Rooksby, Phil. Mag. **15**, 810, 1933.

3) W. G. Burgers, loc. cit. The diagrams showed no lines due to metallic barium, the proportion of barium in the mixed crystals being far too small.

If, however, on spraying the cathode a mixed crystal of the carbonate is present at the outset, it may be expected that the solid solution of oxides will be formed directly by decomposition of this mixed crystal and as a result the interdiffusion of the oxides is eliminated. A carbonate mixture precipitated from a solution containing both Ba and Sr ions, e.g. a mixture of their nitrates, appears suitable for this purpose; as shown by the X-ray photograph in *fig. 3*, such a solution does indeed give a mixed crystal of $BaCO_3$ and $SrCO_3$.

13. Nickel-iron alloy

The next example is of the same class as the one just discussed. X-ray photographs confirmed the conclusion drawn from microscopic examination, that mixed crystals are formed on precipitating a mixture of nickel oxalate and iron oxalate from a solution of nickel chloride and iron chloride. The oxide obtained on heating the precipitate gives on reduction a nickel-iron powder composed of a solid solution of iron and nickel. In this way, therefore, a nickel-iron alloy is directly obtained.

14. Fluorescent Preparations for Luminescent Tubes and Fluorescent Screens

Zinc sulphide containing a varying proportion of cadmium sulphide is in common use as a fluorescent preparation, the colour of the latter being determined by the relative proportions of the two substances. These substances are isomorphous and form mixed crystals in all proportions. By comparing X-ray photographs of these preparations with standard diagrams of the separate sulphides, the approximate composition of the preparations can be readily determined (to within several per cent).

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

No. 1072: R. Houwink: The strength and modulus of elasticity of some amorphous materials, related to their internal structure (Trans. Faraday Soc. **32**, 133-141, Jan. 1936).

A general discussion is given of the tensile strength and the modulus of elasticity of matter on the basis of the cohesive forces of matter. The principal theories regarding the internal structure of asphalts, resins and glass are briefly outlined. The elastic properties particularly of hardening resins are studied. For a phenol-formaldehyde resin, a modulus of elasticity of 1050 kg per sq. mm and a tensile strength of 7.8 kg per sq. mm were found at 195 deg. C. This tensile strength is only 1/550th of the theoretical value (cf. **No. 1071** by J. H. de Boer). An explanation is offered by assuming the occurrence of irregularities ("Lockerstellen") in the structure of the macro-molecules of the resin. Causes responsible for the presence of these "Lockerstellen" are enumerated and discussed, both for resins and for other amorphous substances, e.g. glass. For the modulus of elasticity the measured value is 1/10th of the theoretical value. That this difference is so many times smaller than in the case of the tensile strength is probably due to the part which the secondary bonds (resulting from Van der Waals' forces) play in addition to the primary bonds in the macro-molecules of the resin.

No. 1073: R. Houwink: High elasticity of three-dimensionally polymerised amorphous materials in relation to their internal structure (Trans. Faraday Soc. **32**, 131-143, Jan. 1936).

In this paper the relationship is given between the maximum elastic energy which can be stored in a substance and the energy content of the bonds. In particular the elastic properties of hardening resins are discussed. A high possible elastic deformation (up to 240 per cent) is found at a definite degree of polymerisation of the resin (B state) at a temperature of 120 deg. C. The relationship between these elastic properties and the formation of insoluble, elastic three-dimensional networks is given. A similar behaviour may be observed with asphalt and glass, but it is not so pronounced as with the resins. With these former substances the highest possible elastic deformation is only of the order of 20 per cent. It is shown that a highest possible elastic deformation of this order may generally occur with amorphous substances if the viscosity is of the order of 10^{11} to 10^{13} poises (1 poise = 1 dyne cm^{-2} sec). Calculations are given to explain the changes which occur in Young's modulus, in the tensile strength and in the yield point when matter is transformed from a compact to an open reticulated structure. From the bonding energy which is stored in the intramolecular bonds in asphalt, glass and resins, the author attempts to give a rough explanation for the high possible elastic deformation of these materials.

No. 1074: W. Elenbaas: Über die mit den wassergekühlten Quecksilber-Super-Hochdruckröhren erreichbare Leuchtdichte (Z. techn. Phys., **17**, 61-62, Febr., 1936).

It is shown in this article that in ultra-high pressure mercury vapour discharge tubes equipped with water cooling the brightness hitherto attained can be further increased by reducing the internal and external diameters of the tubes. In the first place the power input and the pressure are kept constant; the brightness increases slightly less than would be proportional to $1/R$ (R = radius). By reducing the internal diameter to 1 mm and with an input of 1400 watts per cm length of the tube (805 volts and 2.1 amp) brightness values of 180 000 candles per sq. cm have been obtained.

No. 1075: M. J. O. Strutt: Diode frequency changers (Wirel. Eng., **13**, 73-80, Febr. 1936).

In this article the most important properties of diode frequency changers are set forth theoretically and experimentally. The conversion gain is $g = R/(R + R_i)$, where R is the tuned impedance on the primary side of the intermediate frequency transformer and R_i the effective internal resistance of the diode for the incoming signal. If oscillator voltages of over 4 volts are used and a proper bias applied to the diode, the value of R_i may be about 0.1 megohm. Owing to the low input impedance, it is preferable to use the diode in sets with a high-frequency valve before it. In this case the noise due to shot effect is negligible; whistling noises are sufficiently low if the input signal amplitude on the diode is only a few millivolts, while at the same time distortion effects are negligible. Compared to the octode, the diode circuit for frequency changing generally offers the advantage that it is more suitable for short waves. Contrary to other mixers, higher harmonics of the oscillator frequency for frequency changing can also be used with this diode circuit without loss of gain, as may be sometimes advisable for short waves.

No. 1076*: W. F. Brandsma: Het onderzoek van de beitelpunt (Metaalbewerking, **2**, 541-545, Febr. 1936).

This article describes the application of the so-called facing-lathe test by means of which the quality of a cutting tool edge can be determined. In these tests the distance from the shaft is measured at which the tool loses its edge when a disk rotating at a uniform angular velocity is turned by the tool from the centre towards the periphery. A fuller abstract of this paper will be omitted here as this subject is dealt with in detail in a separate series of articles appearing in this journal (Philips techn. Rev., **1**, 183 and 200, 1936).

No. 1077: Balth. van der Pol: On oscillations (Norsk Rikskringkastings Forelesninger, Oslo, 1936, pp. 243-275).

This paper presents a general mathematical review of the principal properties of oscillations which are of interest in different branches of science and technology. In addition to standard functions represented by a sinusoidal time diagram, special attention is also directed to functions with a rectangular time diagram, for which, analogous to ordinary sine functions, an orthogonal system of functions can also be derived, thus permitting an ordinary sine function to be expanded on the basis of these functions. After discussing those oscillations which can be represented by linear differential equations, the author passes to a consideration of non-linear phenomena. The relationship between harmonic and so-called relaxation oscillations is analysed. The paper concludes with a discussion of various types of relaxation oscillations of frequent occurrence in nature and technology, such as the beat of the heart, the multivibrator of Abraham and Bloch and the so-called "sleeping actions" of plants.

(A translation of these papers appeared in Ned. T. v. Natuurk., **3**, pp. 65-85 and 97-108, 1936).

No. 1078: J. L. Snoek: On the "Permalloy Problem" (Nature, **137**, 493, 1936).

According to Lichtenberger the exceptionally high permeability of Permalloy may be ascribed to the fact that three particular points in the iron-nickel system are situated close together; at 71 per cent the crystal anisotropy vanishes; at 82 per cent the absolute value of magnetostriction passes through a minimum, and at 85.5 per cent the anistropy of magnetostriction also vanishes. Various recent researches carried out by the author and other investigators lead the former to conclude that Lichtenberger's hypothesis is valid. On slow cooling in the absence of a magnetic field magnetostriction is able to disturb the magnetic orientation, resulting in a lower permeability. If on the other hand slow cooling takes place in the presence of a magnetic field, the disturbance due to magnetostriction is eliminated in the direction of this field and the action of crystal anisotropy becomes much more pronounced.

No. 1079: K. F. Niessen: Erdabsorption bei vertikalen Dipolantennen in grosser Höhe über ebener Erde (Ann. Physik, **25**, 673-687, Apr., 1936).

For the case where the quotient of the heitgh h of a vertical dipole-aerial above the ground and the radiated wave length satisfies a certain inequality, the author deduces a formula for that fraction T of the total energy radiated from the aerial which is absorbed by the earth. This absorbed portion is determined by the absolute value n and the argument of the complex refractive index and hence by the dielectric constant and by the conductivity of the soil. Simple formulae are given for the practical case where $1/n^3$ can be neglected compared with unity. The absorbed portion T at a finite height h of the dipole aerial is greater than $T(\infty)$ for an infinite height. This additional absorption due to placing the aerial at height h may be expressed as a function of h/λ. From this expression it follows that it is of advantage to locate the dipole aerial at a height which is equal to an odd multiple of the quarter wave length, whilst practically no further gain accrues when the aerial is located at a height of more than four wave-lengths above the ground.

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*) A sufficient number of reprints for purposes of distribution is not available of those publications, marked with an asterisk *). Reprints of other publications may on application be obtained from Philips laboratory, Kastanjelaan, Eindhoven, Holland.